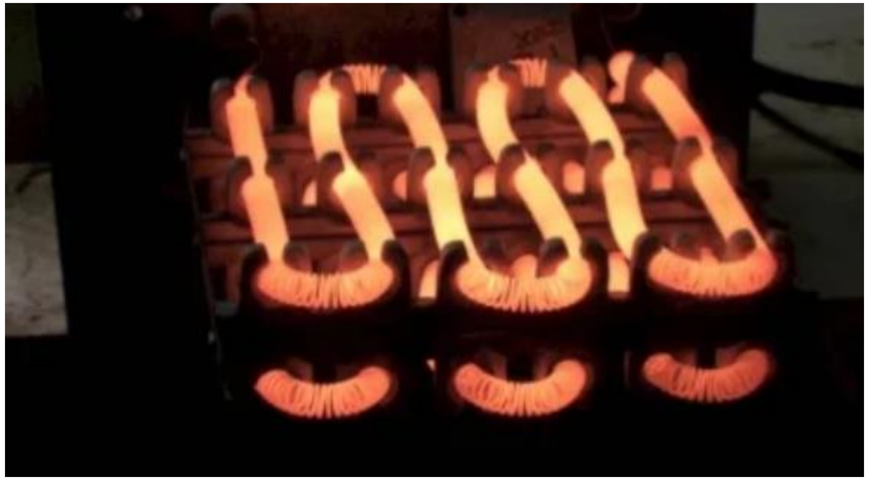


Unit-1: Electric Heating and Welding

2EEDE02: Electrical Power Utilization and Safety

Introduction

- Heat plays a major role in everyday life.
- All heating requirements in **domestic** purposes such as cooking, room heater, immersion water heaters, electric toasters.
- **Industrial** purposes such as welding, melting of metals, tempering, hardening, and drying can be melt 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 heating* is considered far **superior** compared to the heat produced by coal, oil, and natural gas.

- **Electric heating** is a process in which electrical energy is converted to heat.

1. When current is passed through a conductor, the conductor becomes hot (**resistance** heating).
2. When a magnetic material is brought in the vicinity of an alternating magnetic field, heat is produced in the magnetic material (**induction** heating).
3. When an electrically insulating material was subjected to electrical stresses; it too underwent a temperature rise (**dielectric** heating).

Advantages of Electric Heating

- Economical: Electric heating equipment is cheaper; they do not require much skilled persons; therefore, maintenance cost is less.
- Cleanliness: Since dust and ash are completely eliminated in the electric heating, it keeps surroundings clean.
- 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.
- Ease of control: In this heating, temperature can be controlled and regulated accurately either manually or automatically.
- Uniform heating: The substance can be heated uniformly throughout whether it may be conducting or non-conducting material.

- High efficiency: In non-electric heating, only 40-60% of heat is utilized but in electric heating 75-100% of heat can be successfully utilized. So, overall efficiency of electric heating is very high.
- Automatic protection: Protection against over current and overheating can be provided by using control devices.
- Heating of non-conducting materials: The heat developed in the non-conducting materials such as wood and porcelain is possible only through the electric heating.
- Better working conditions: No irritating noise is produced with electric heating and also radiating losses are low.
- Less floor area: Due to the compactness of electric furnace, floor area required is less.
- High temperature: High temperature can be obtained by the electric heating except the ability of the material to withstand the heat.

Disadvantages

- The **cost** of electricity makes it expensive to use as a heating fuel.
- With space heaters, we can't easily provide central **filtration, humidification or cooling**.
- The electrical hazard of **shock** and **fire** caused by electricity is an issue.
- There are a cost associated with Electric heat requires a **larger electrical service** than normal.

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

- One molecule of substance gets heated and transfers the heat to the adjacent one and so on.
- 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.
- Ex: Refractory heating, the heating of insulating materials, etc.

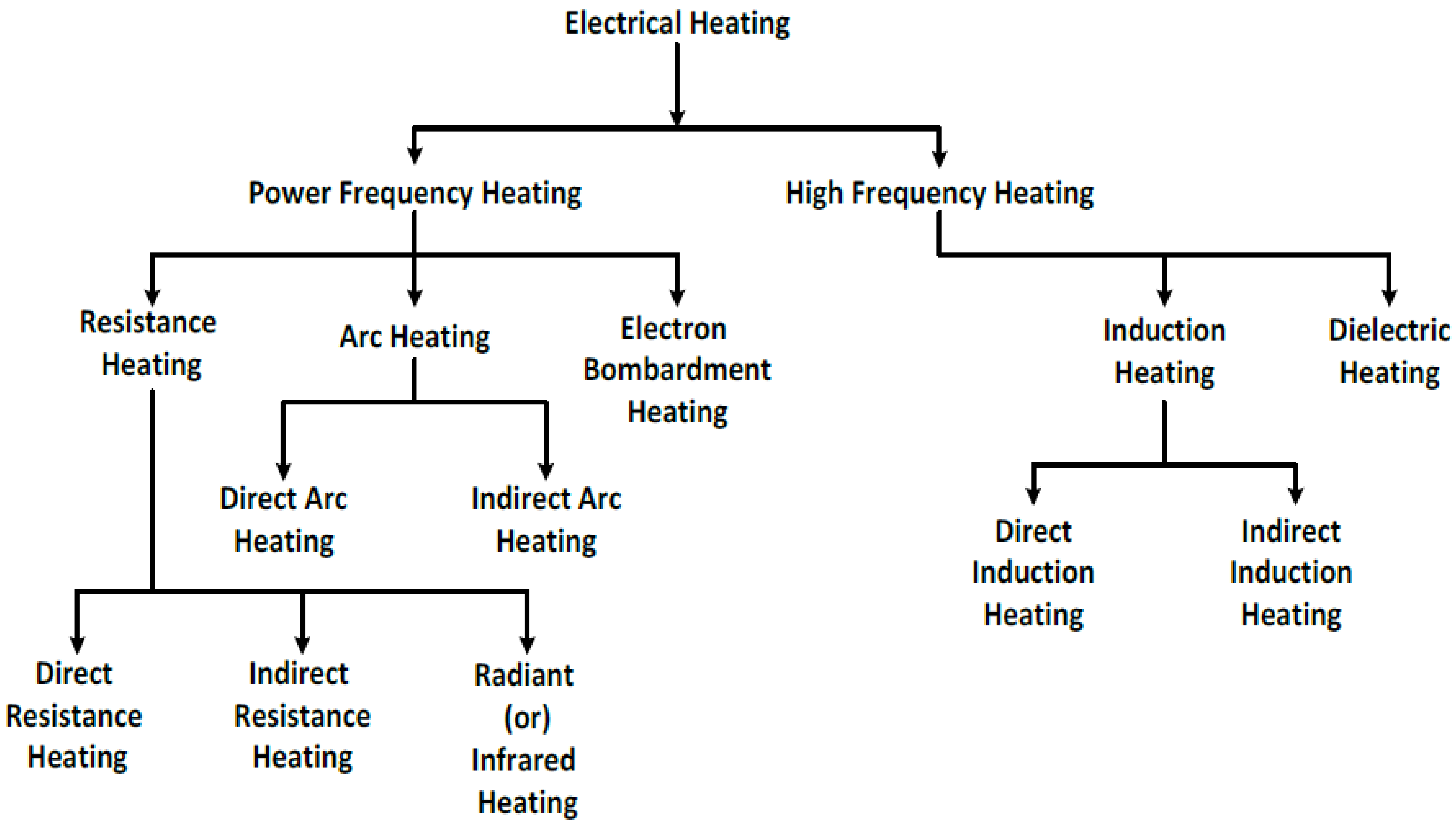
2. Convection

- 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 heat depends mainly on the difference in the fluid density at different temperatures.
- The quantity of heat absorbed from the heater by convection are depends on temperature of the heating element above the surrounding, size of surface of heater, on the position of heater.
- Ex: Immersion water heater.

3. 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.
- Rate of heat radiation is given by Stefan’s law.
- Ex: Solar heaters.

Classification of Electric Heating Method



HEATING ELEMENT MATERIALS

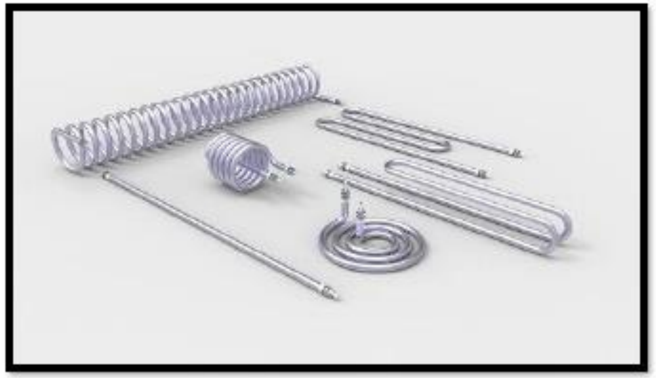
Indirect resistance furnaces use many different types of heating elements for producing heat. A good heating element should have the following properties :

1. **High Specific Resistance (or High Resistivity):** When specific resistance of the material of the wire is high, only short length of it will be required for a particular resistance (and hence heat) or for the same length of the wire and the current, heat produced will be more.
2. **High Melting Temperature:** If the melting temperature of the heating element is high, it would be possible to obtain higher operating temperatures.
3. **Low Temperature Coefficient of Resistance**: In case the material has low temperature coefficient of resistance, there would be only small variations in its resistance over its normal range of temperature. Hence, the current drawn by the heating element when cold (i.e., at start) would be practically the same when it is hot.
4. **High Oxidising Temperature**: The element material should not be oxidized when it is subjected to high temperatures; otherwise the formation of oxidized layers will shorten its life.

5. **Positive Temperature Coefficient of Resistance:** If the temperature coefficient of the resistance of heating element is negative, its resistance will decrease with rise in temperature and it will draw more current which will produce more wattage and hence heat. With more heat, the resistance will decrease further resulting in instability of operation.

6. **Ductile:** Since the material of the heating elements has to have convenient shapes and sizes, it should have high ductility and flexibility.

7. **Mechanical Strength**. The material of the heating element should posses high mechanical strength of its own. Usually, different types of alloys are used to get different operating temperatures.



DESIGN OF HEATING ELEMENT

- Heating elements sound very simple and straightforward, but there are, many different factors that engineers have to consider in designing them.
- There are roughly 20 – 30 different factors that affect the performance of a typical heating element, including obvious things like the **voltage and current, the length and diameter of the element, the type of material, and the operating temperature.** There are also specific factors you need to consider for each different type of element.
- Normally, wires of circular cross-section or rectangular conducting ribbons are used as heating elements.
- **The size and length of wire can be obtained if the wattage of the heating element is known and if the operating voltage and ambient temperature and heating element temperatures are known.**

- Under steady-state conditions, a heating element dissipates as much heat from its surface as it receives the power from the electric supply. If **P** is the power input and **H** is the heat dissipated by radiation, then **P = H** under steady-state conditions.
- **Alternatively speaking**, initially when the heating element is switched on to supply, the temperature goes on increasing and finally a high a steady state temperature is reached when it can be assumed that practically all the heat is being transferred through radiations.

As per Stefan's law of radiation, heat radiated by a hot body is given by

$$H = 5.72\, eK \left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right] \mathrm{W/m^2}$$

where T_1 is the temperature of hot body in $°K$ and T_2 that of the cold body (or cold surroundings) in $°K$

Note:

T_K : Temperature in Kelvin (K)
T_C : Temperature in Celsius (°C)

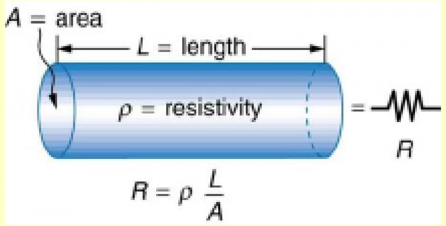
$T_K = T_C + 273.15$

$T_C = T_K - 273.15$

K = radiant efficiency = 1 for single element
= 0.5 to 0.8 for more than element
e = emissivity = 1.0 for black body
= 0.9 for resistance heating element

Let V be the supply voltage of the system and R be the resistance of the element, then electric power input, $P = \dfrac{V^2}{R}$ W.

If ρ is the resistivity of the element, l is the length, a is the area, and d is the diameter of the element, then:



$$R = \rho\frac{l}{a} = \frac{\rho l}{\frac{\pi d^2}{4}}.$$

Therefore, power input, $P = \dfrac{V^2\pi d^2}{4\rho l}$. **(1)**

By rearranging the above equation, we get:

$$\frac{l}{d^2} = \frac{\pi V^2}{4P\ \rho}, \qquad \textbf{(2)}$$

where P is the electrical power input per phase (watt), V is the operating voltage per phase (volts), R is the resistance of the element (Ω), l is the length of the element (m), a is the area of cross-section (m^2), d is the diameter of the element (m), and ρ is the specific resistance (Ω-m).

The surface area of the circular heating element:

$$S = \pi d l.$$

$$\therefore \text{Total heat dissipated} = \text{surface area} \times H$$

$$= H\pi d l.$$

Under thermal equilibrium,

Power input = heat dissipated

$$P = H \times \pi d l.$$

Substituting P from Equation (1) in above equation:

$$\frac{V^2}{\rho\, l}\left(\frac{\pi\, d^2}{4}\right) = H \times \pi\, d l$$

$$\therefore \frac{d}{l^2} = \frac{4\,\rho\,H}{V^2}. \qquad \textbf{(3)}$$

By solving Equations (2) and (3), the length and diameter of the wire can be determined.

The above explanation is for circular type heating element.

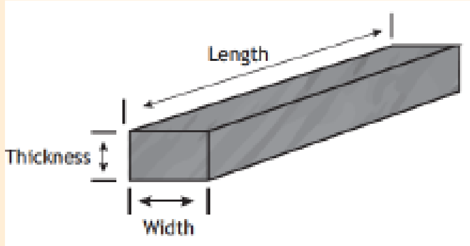
RIbbon-type element

Let w be the width and t be the thickness of the ribbon-type heating element.

Electrical power input $P = \dfrac{V^2}{R}$.

We know that, $R = \dfrac{\rho l}{a} = \dfrac{\rho l}{w \times t}$ (for ribbon or rectangular element, $a = w \times t$)

$$\therefore P = \frac{V^2}{\left(\dfrac{\rho\, l}{w \times t}\right)}$$



$$\therefore \frac{l}{w} = \frac{V^2\ t}{P\ \rho}. \qquad \text{..(1)}$$

The surface area of the rectangular element $(S) = 2\, l \times w$.

(Neglecting the Side Area ***2tl*** as the thickness is negligible)

The surface area of the rectangular element $(S) = 2\,l \times w$.

$\therefore$ Total heat dissipated $= H \times S$

$$= H \times 2\,lw.$$

$\therefore$ Under the thermal equilibrium,

Electrical power input $=$ heat dissipated

$$P = H \times 2\,lw$$

$$lw = \frac{P}{2\,H}. \qquad \text{.....(2)}$$

By solving Equations **(1)** and **(2)** , the length and width of the heating element can be determined.

Numericals Pertaining to Design of Heating Element

Ques: A resistance oven employing nichrome wire is to be operated from 220 V single-phase supply and is to be rated at 16 kW. If the temperature of the element is to be limited to 1,170°C and average temperature of the charge is 500°C, find the diameter and length of the element wire.

Radiating efficiency = 0.57, Emissivity=0.9, Specific resistance of nichrome wire = (109×10^{-8}) (Ω-m)/ ohm-m.

Solution. $P = 16\text{ kW} = 16{,}000\text{ W}$

As we know that, $$\frac{l}{d^2} = \frac{\pi V^2}{4\rho P} = \frac{\pi \times (220)^2}{4 \times 109 \times 10^{-8} \times 16{,}000} = 2{,}179{,}660 \qquad \dots (i)$$

Now, $$H = 5.72 eK \left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right] W/\text{m}^2 = 5.72 \times 0.9 \times 0.57 \left[\left(\frac{1443}{100} \right)^4 - \left(\frac{773}{100} \right)^4 \right]$$

$$= 116{,}752\text{ W/m}^2$$

Now, total heat dissipated/s = electrical power input

$$\therefore \quad (\pi d) \times l \times 116{,}752 = 16{,}000; \quad \therefore \quad dl = 0.0436$$

or $\quad d^2 l^2 = 0.0019$ ...*(ii)*

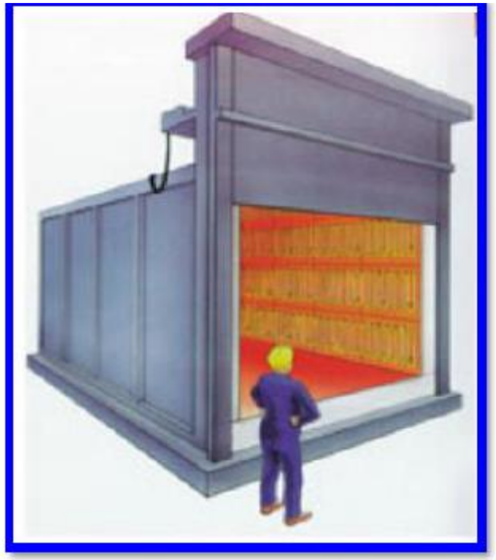
From Eqn. (*i*) and (*ii*), $l^3 = 2{,}179{,}660 \times 0.0019 = 4141$

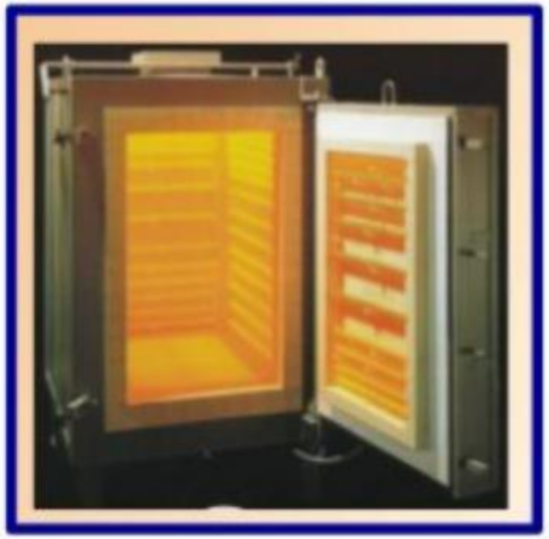
$\therefore \quad l = \mathbf{16.05\ m}$ **Answer**

$d = 0.0436/16.05 = 2.716 \times 10^{-3}\ \text{m} = \mathbf{2.716\ mm}$ **Answer**

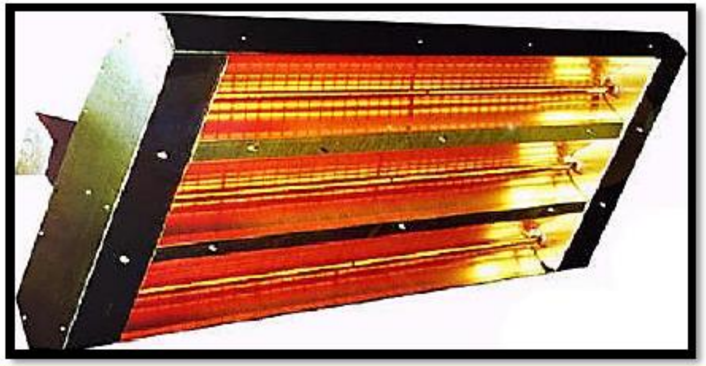
Ques (for Students' Practice): A 20-kW, 230-V, and single-phase resistance oven employs nickel - chrome **strip** 25-mm thick is used, for its heating elements. If the strip temperature is not to exceed 1,200 ^{0}C and the temperature of the charge is to be 700 ^{0}C. Calculate the width and length of the strip. Assume the radiating efficiency as 0.6 and emissivity as 0.9. Determine also the temperature of the strip when the charge is cold. Specific Resistance of the strip is taken as 1.106×10^{-6} (Ω-m) **(Answer: l = 7.435 m; w = 11.42 mm; T = 1124.9 ^{0}C)**

Ques (for Students' Practice): A 30-kW, 3-φ, 400-V resistance oven is to employ nickel-chrome strip 0.254 mm thick for the three star-connected heating elements. If the wire temperature is to be 1,100°C and that of the charge to be 700°C, estimate a suitable width for the strip. Assume emissivity = 0.9 and radiating efficiency to be 0.5 and resistivity of the strip material is 101.6×10^{-8} Ω - m. **(Answer: w = 7.4 mm; T = 1124.9 ^{0}C)**



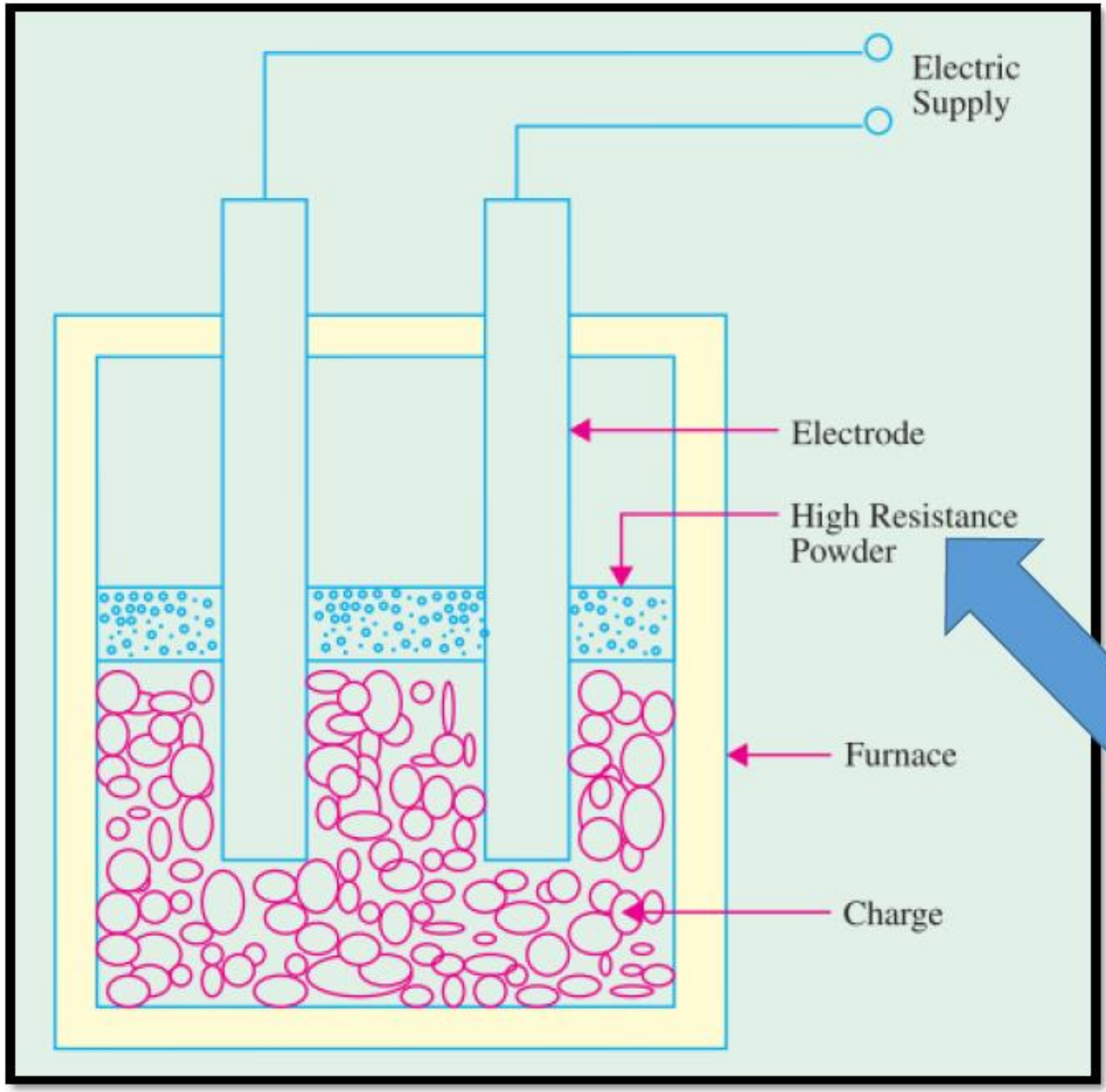


Resistance Heating



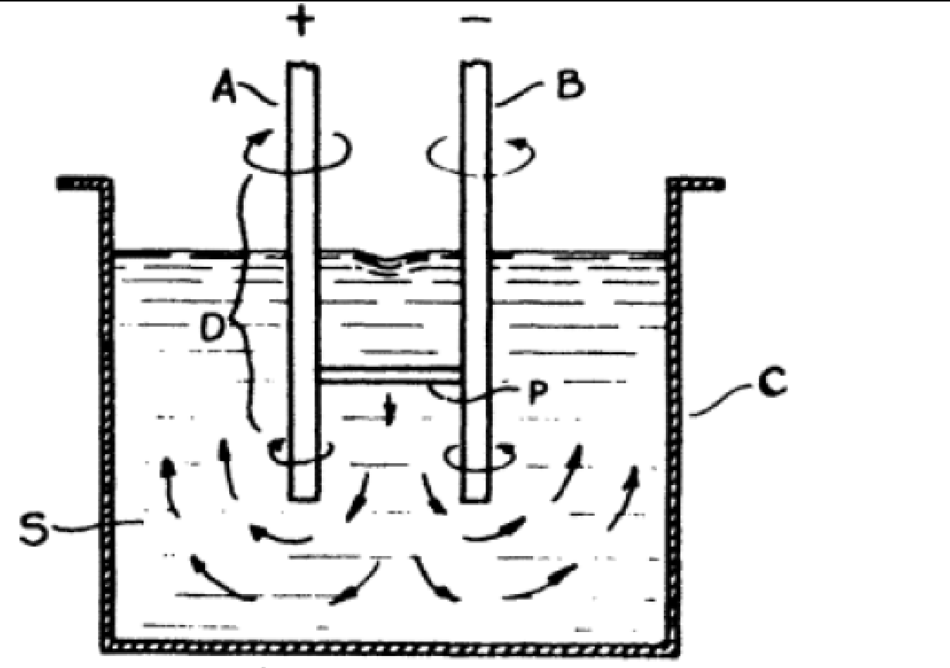
Infrared Heaters

DIRECT RESISTANCE HEATING



- Resistance heating uses the heat generated by Joule effect in a conductive body, metallic or non-metallic, in which an electrical current flows.
- In direct resistance heating, **the workpiece (or charge)** to be heated is treated as a resistance and current is passed through it. The charge may be in the form of powder, small solid pieces or liquid. The two electrodes are inserted in the charge and connected to either a.c. or d.c.
- Obviously, two electrodes will be required in the case of d.c. or single-phase a.c. supply but there would be three electrodes in the case of 3-phase supply.
- When highly conductive metals are to be heated, insertion of electrodes into **charge or workpiece** would now mean short circuit. To avoid this, in such cases, highly resistive powder is sprinkled in between the surfaces of pieces. More heat is, therefore, produced at these contacts surfaces.

- The direct resistance heating method is employed in salt bath furnaces and in electrode boiler for heating water.
- Salt bath furnaces are used for the purposes of carbonizing, tempering, quenching and hardening of steel tools.

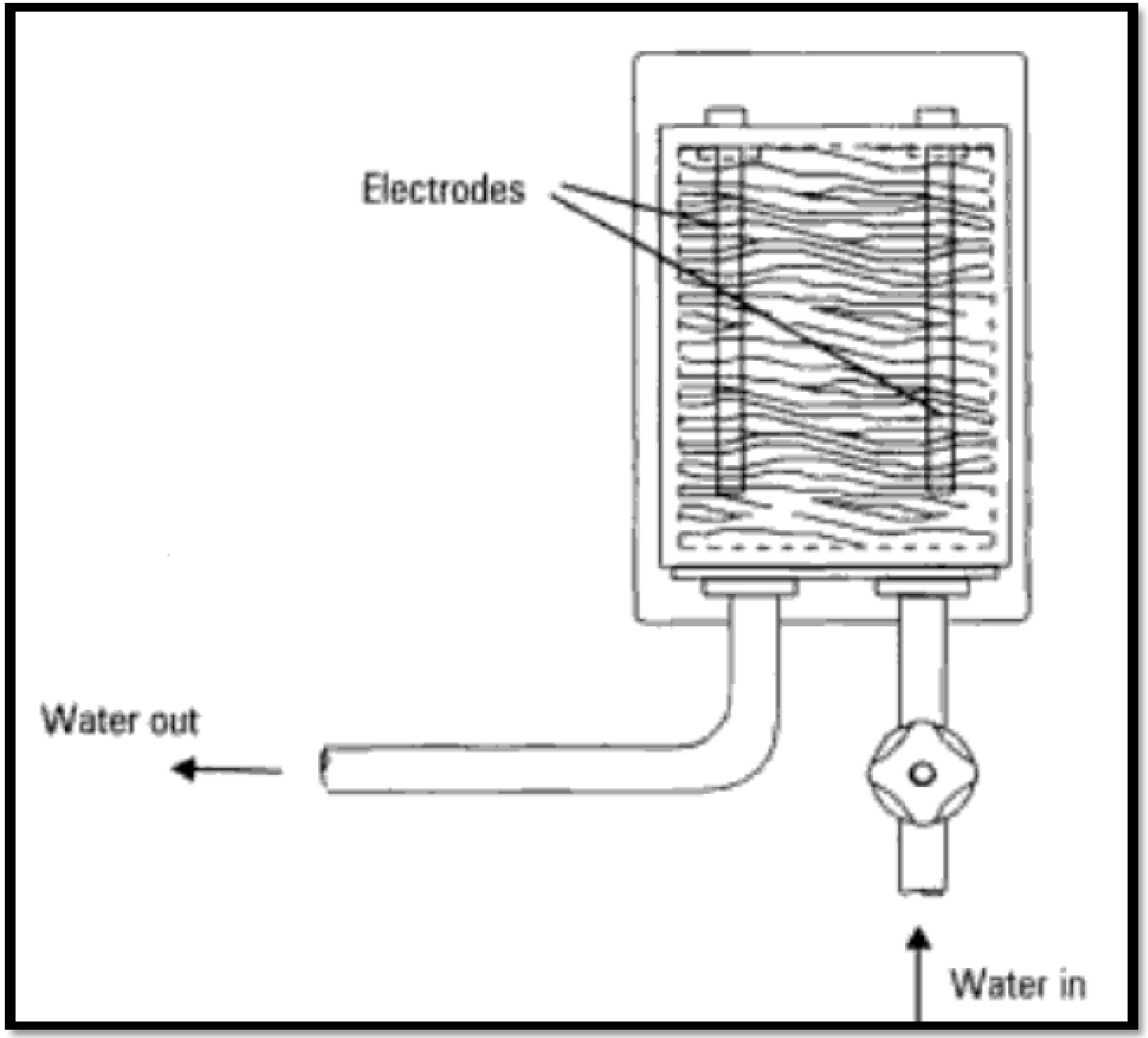


1. General arrangement of salt bath furnace.

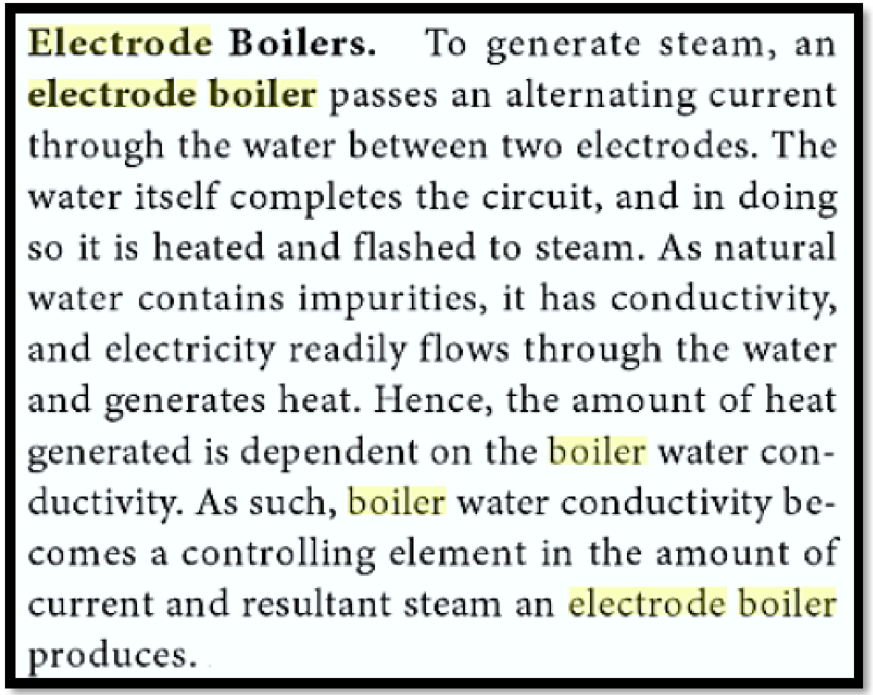
- Electric salt bath furnaces consist of a container to hold the molten salt and one or more pair of electrodes for releasing the electrical energy as heat in the bath. A current is physically passed from one electrode to the other through the salt.
- At any instant when current is flowing the electrical system will be as shown. Current flows down electrode A, through the salt by any path P, and up electrode B. Electrodes are sized and spaced so that the only significant resistance is in the path through the salt. This means that the energy is released as heat in that path. When a part to be treated is placed in the furnace, it is immediately surrounded by molten salt.
- Salt such as nitrates, nitrites, caustic soda, chlorides, carbonates, and cyanide. Mixtures of salt are selected to give a specific temperature range and a desired treatment (or lack of treatment) to the surface of the material being processed.

Molten salt baths offer several distinct advantages:

- salts are available for operation in the temperature range of 175 to 1260 ^{0}C (350 to 2300 ^{0}F);
- parts do not scale or otherwise result in deteriorated surfaces because they are fully protected while they are in the molten bath;
- a wide variety of salts are available, including salts that change the surface chemistry of the steel; and
- gives rapid and uniform heating

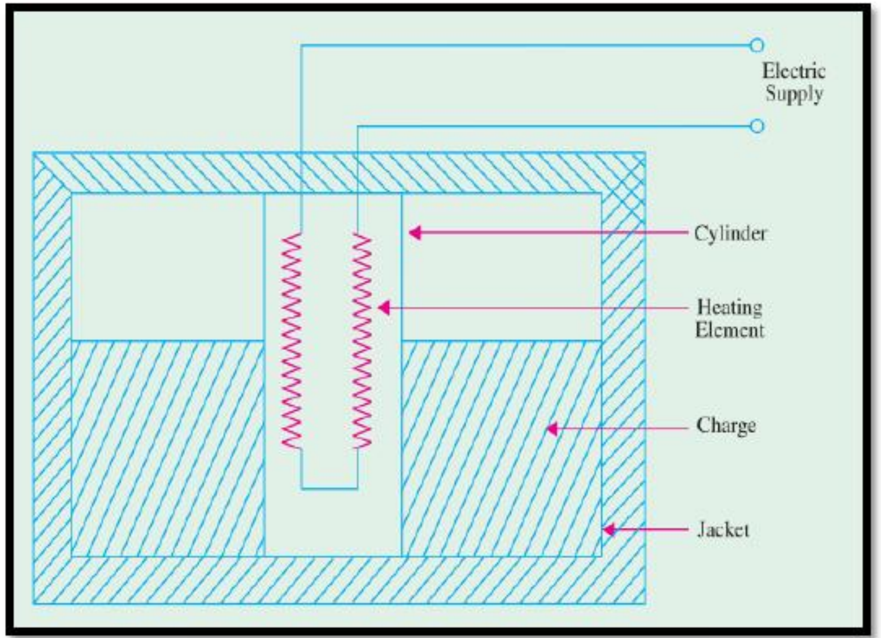


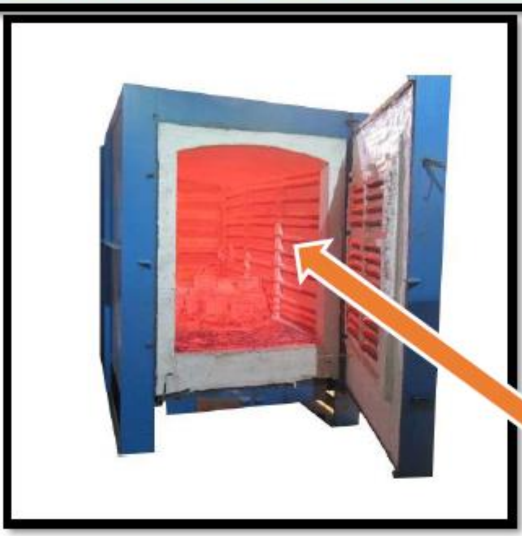
- **Electrode steam boiler** work on the principle of passage of electricity through water, which causes a rise in the temperature of water. It comprises of an insulated boiler vessel, special alloy electrodes, feed water pump, various mountings and fittings along with an electrical control panel.



Electrode Boilers. To generate steam, an **electrode boiler** passes an alternating current through the water between two electrodes. The water itself completes the circuit, and in doing so it is heated and flashed to steam. As natural water contains impurities, it has conductivity, and electricity readily flows through the water and generates heat. Hence, the amount of heat generated is dependent on the boiler water conductivity. As such, boiler water conductivity becomes a controlling element in the amount of current and resultant steam an electrode boiler produces.

INDIRECT RESISTANCE HEATING





- In Indirect Resistance Heating Method, electric current is passed through an element of high resistance. Passage of an electric current through resistance produces "I^2R loss" which manifests itself in the form of heat. Heat is then transferred from the heating element to the **charge or workpiece** mainly by radiation and convection.
- Examples include room heater, hair drier, soldering iron, flat iron, immersion heater etc.

DIFFERENCE BETWEEN OVEN AND FURNACE

OVEN

- Ovens are primarily used for **warming, drying, and tempering.**
- The maximum operating temperatures of ovens are from incubators at about **70°C** to annealing ovens and tempering ovens with increasing temperatures up to **650°C** maximum.

FURNACE

- In industrial settings, furnaces are used **to heat treat metals as well as process other materials.**
- A furnace is an industrial heating system that heats above **535°C (1000°F).**
- The noticeable difference between ovens and furnaces is that furnaces have linings consisting of **insulating** and **refractory materials**

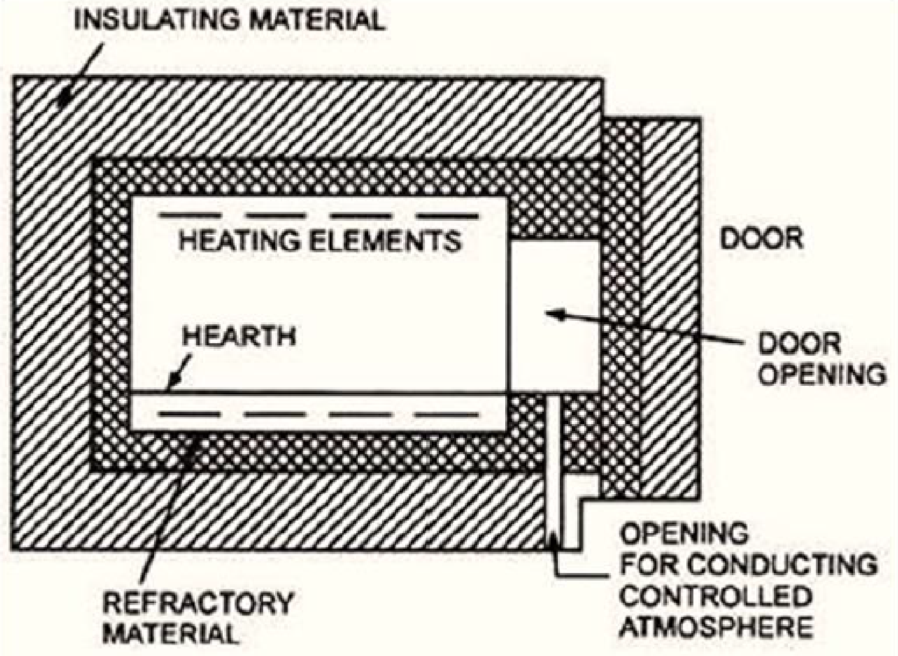
High Temperature Insulating Lining:

1. **Ensure Operator Safety:** The outer body of an industrial furnace can become extremely hot when the furnace has been in use, so operators who are transporting samples in and out of furnaces are at risk of being burnt.
2. When the chamber within the furnace is heated, some of this heat can escape, so more heat is needed to reach the required temperatures. High temperature insulation can reduce the amount of heat dissipation (Heat loss), making the industrial furnace more efficient.

Refractory Lining:

- To withstand very high temperature (1400 to as high as > 2500 ^{0}C.
- Can prevent corrosion to liquid metal, and
- Resistant to hot abrasion and erosion

INDIRECT RESISTANCE HEATING



Resistance Furnace

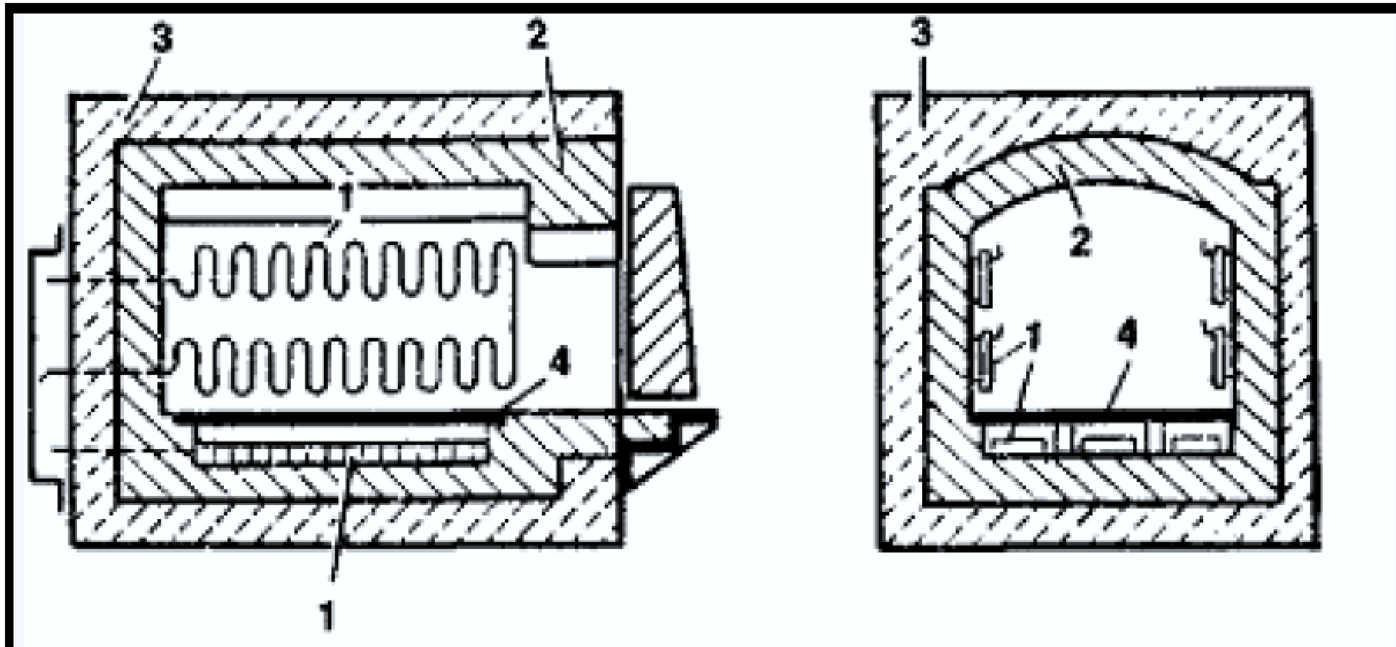
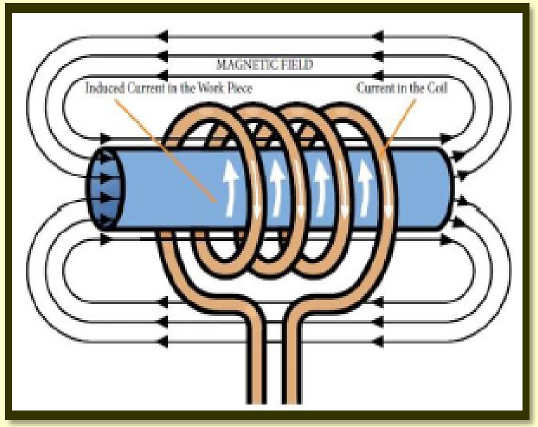


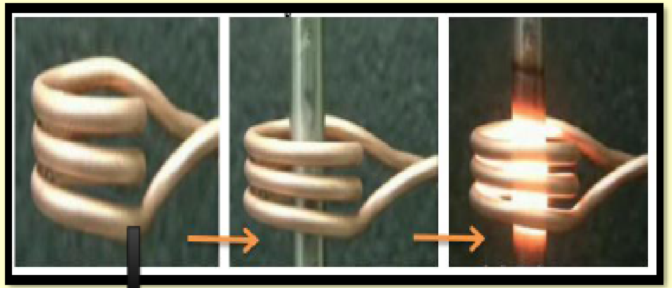
Figure Diagram of a batch-type indirect-heat resistance chamber furnace: (1) heating elements, (2) refractory lining, (3) heat insulation, (4) refractory hearth plate

Hearth Plate: To support a body of conductive material, means for passing through said body an electric current.

INDUCTION HEATING / NON – CONTACT HEATING

- Induction heating systems are developed using electromagnetic induction that was first discovered by **Michael Faraday in 1831**.
- **Electromagnetic induction refers to the phenomenon by which electric current is generated in a closed circuit by the fluctuation of current in another circuit placed next to it.**
- **An induction heating system includes an induction power supply which converts line power to an alternating current, delivers it to a work coil creating an electromagnetic field within the coil. The work piece or charge or object (to be heated) is placed in the coil where this field induces a current in the work piece, which generates heat in the work piece. The work coil does not touch the work piece, and the heat is only generated by the induced current flowing in the work piece.**





Work Coil

Induction heating relies on two mechanisms of energy dissipation for the purpose of heating. These are energy losses due to Joule heating and energy losses associated with magnetic hysteresis.

INDUCTION HEATING

An induction-heating coil surrounding a conducting workpiece is fed with alternating current and the resulting magnetic flux couples with the workpiece. In accordance with Lenz's law, current is induced in the workpiece in such a direction that it attenuates the field of the coil. It is this current, flowing through the resistance of the workpiece, which generates heat.

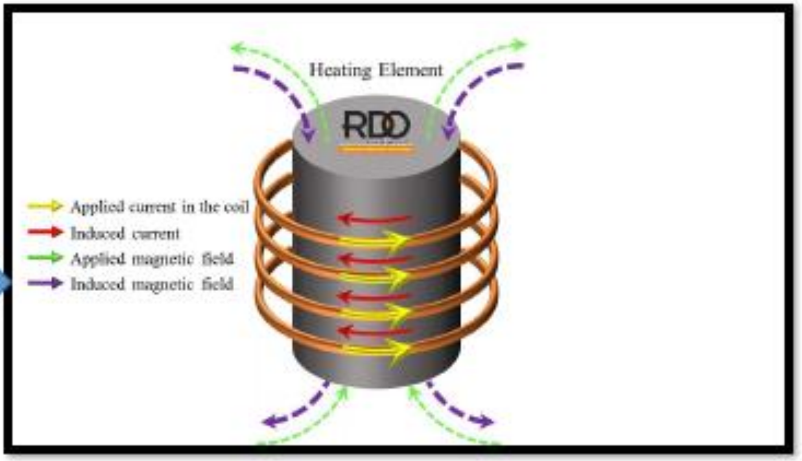
Direct Induction Heating

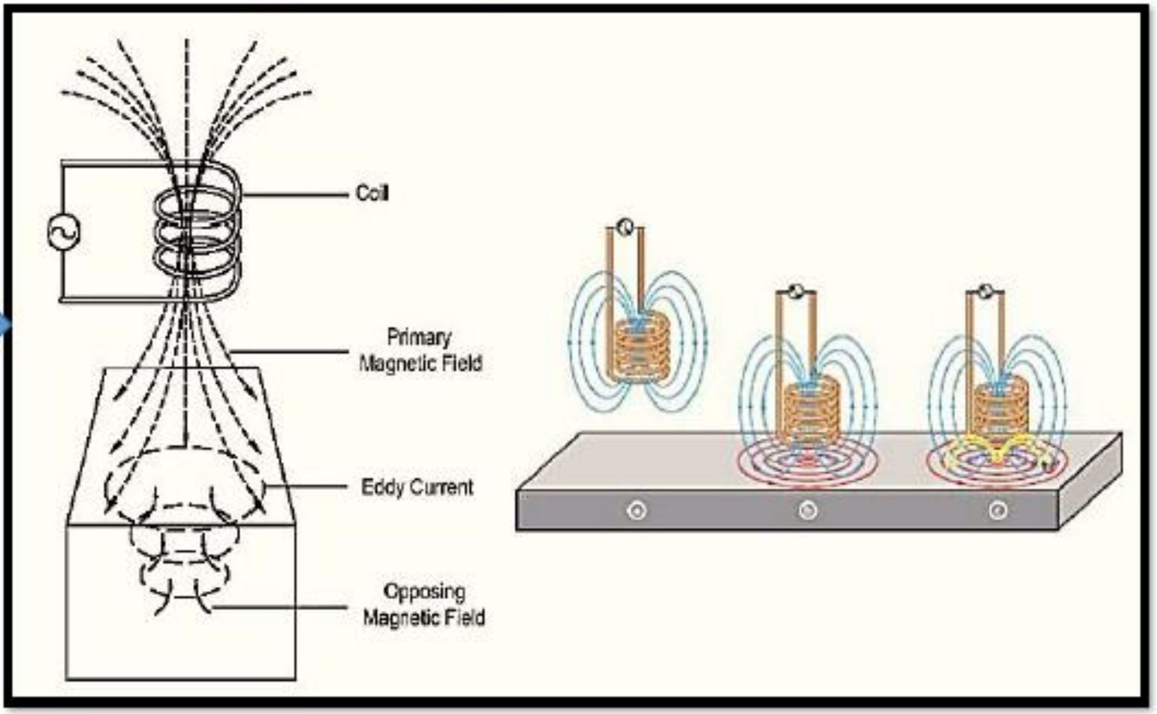
- In this method of heating, the currents are induced by electromagnetic action in the body to be heated. The induced currents when flowing through the resistance of the body to be heated develop the heat and thus raise the temperature.

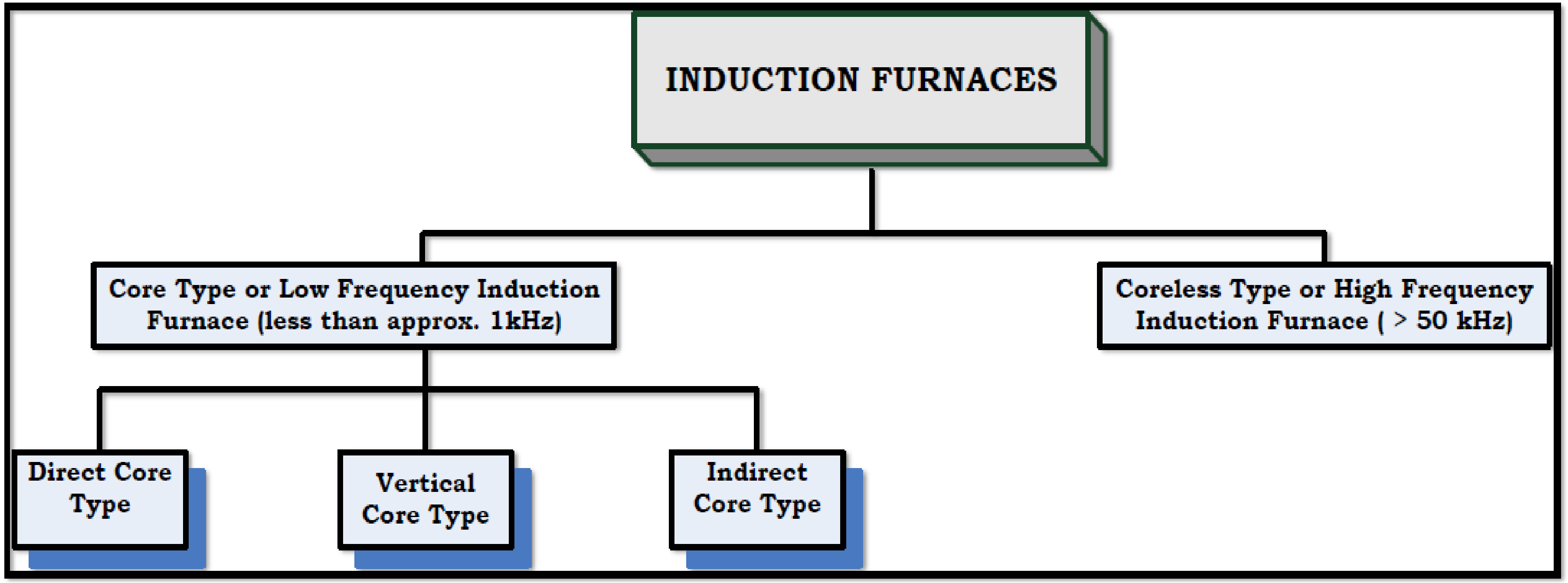
Indirect Induction Heating

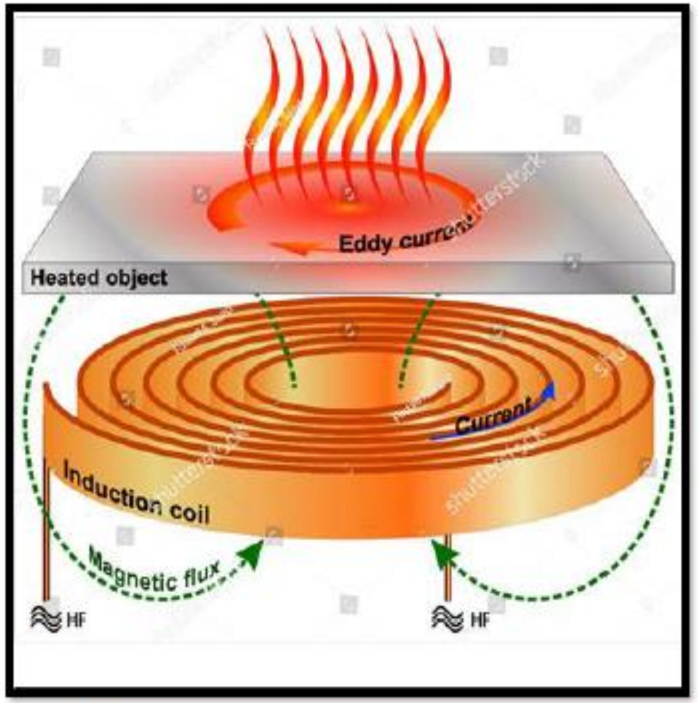
- In this method of heating, the eddy currents are induced in the heating element by electromagnetic action. Eddy currents set up in the heating element produce the heat which is transferred to the body to be heated up, by radiation and convection.

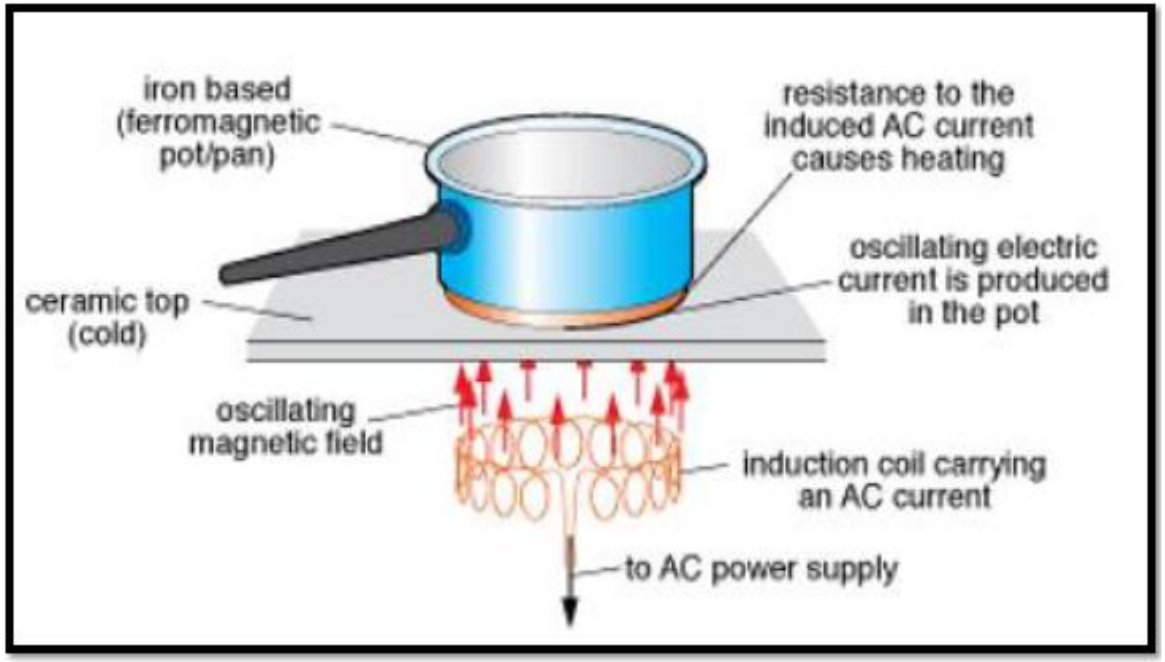
EDDY CURRENTS INDUCED IN THE WORKPIECE






INDUCTION FURNACES
Core Type or Low Frequency Induction Furnace (less than approx. 1kHz)
Coreless Type or High Frequency Induction Furnace (> 50 kHz)
Direct Core Type
Vertical Core Type
Indirect Core Type

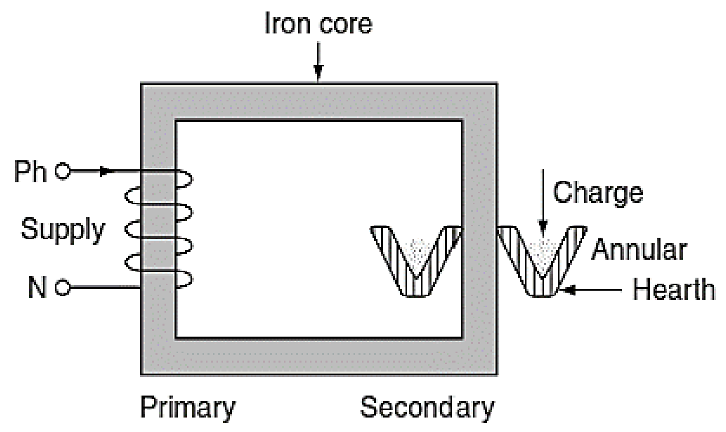




Induction Heating

Induction heating is generally used to heat the `work' directly, that is the induced currents flow in the electrically conducting object being heated.

DIRECT CORE TYPE INDUCTION FURNACE



If the transformer secondary current density exceeds **500 A/cm²** then, due to the interaction of secondary current with the alternating magnetic field, the molten metal is squeezed to the extent that secondary circuit is interrupted (due to constricting forces on the cross – section of the metal). This effect is known as **"pinch effect". The pinch effect is more pronounced at higher frequencies.**

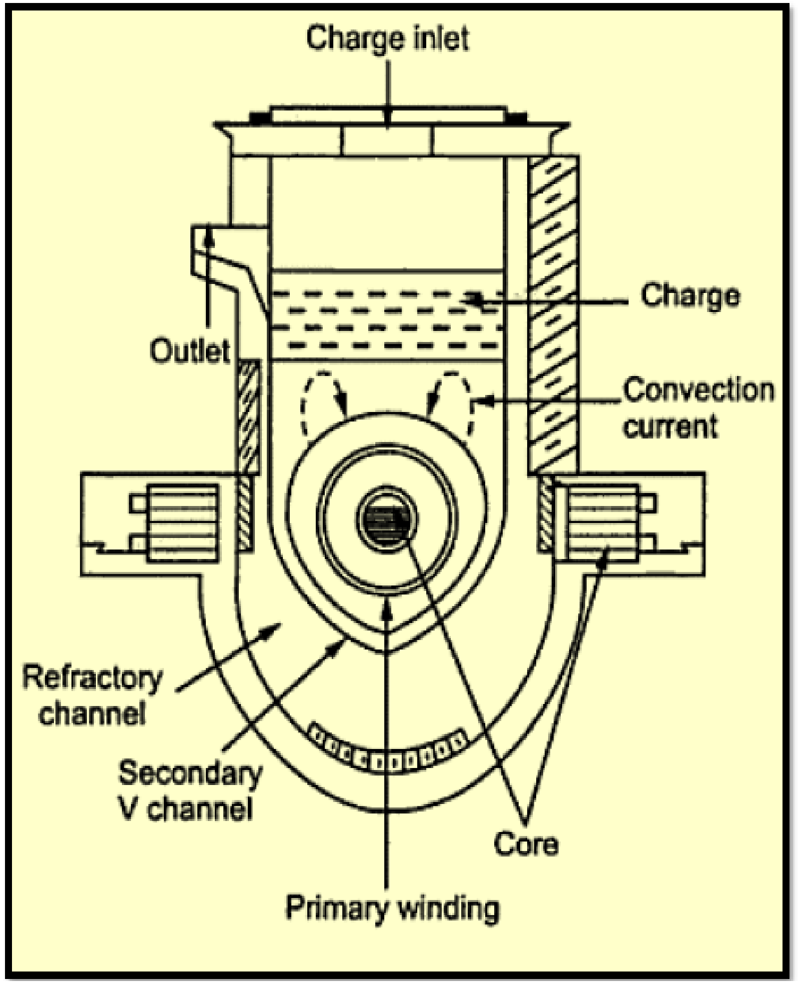
- It is essentially a transformer in which the charge to be heated forms a single-turn short-circuited secondary and is magnetically coupled to the primary by an iron core.
- The furnace consists of a circular hearth which contains the charge to be melted in the form of an annular ring.
- **When there is no molten metal in the ring, the secondary becomes open-circuited there-by cutting off the secondary current. Hence, to start the furnace, molten metal has to be poured in the annular hearth or sufficient molten metal is allowed to remain in the crucible rom the previous operation.**
- Since, magnetic coupling between the primary and secondary is very poor, it results in high leakage and low power factor. This difficulty, however, is overcome by employing supply frequencies as low as **10 Hz** for operation of such furnaces.

Drawbacks of Direct Core Type Induction Furnace:

- It has to be run on low-frequency supply which entails extra expenditure on motor-generator set or frequency convertor.
- It suffers from pinching effect.
- The crucible for charge is of odd shape and is very inconvenient for tapping the molten charge.
- It does not function if there is no molten metal in the hearth i.e. when the secondary is open. Every time molten metal has to be poured to start the furnace.
- It is not suitable for intermittent service.

However, in this furnace, melting is rapid and clean and temperature can be controlled easily. Moreover, inherent stirring action of the charge by electro-magnetic forces ensures greater uniformity of the end product.

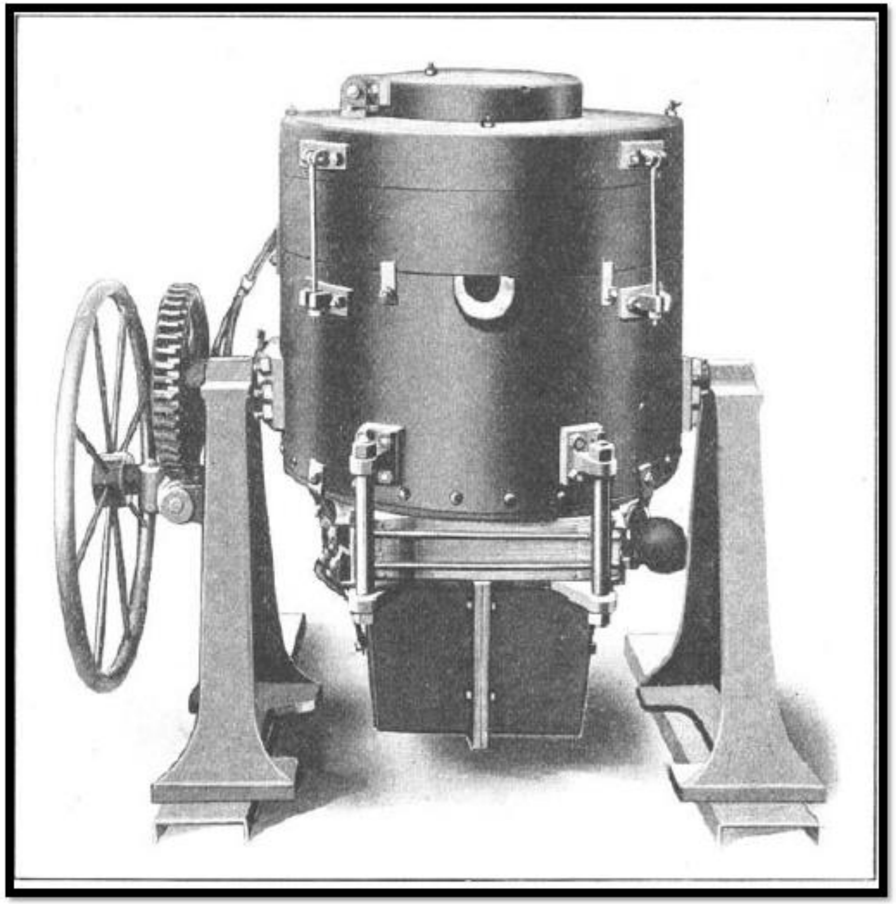
VERTICAL CORE TYPE INDUCTION FURNACE/ AJAX WYATT FURNACE

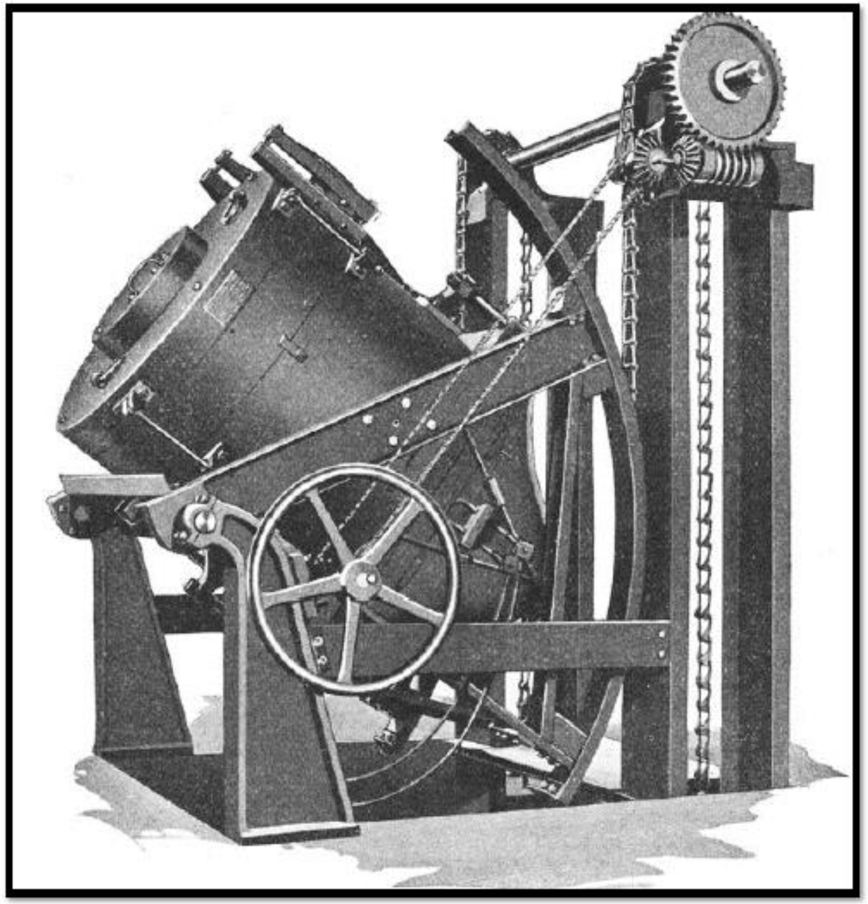


- In order to solve the problems (encountered in direct core type induction furnace i.e. pinch effect) practically, **an American Engineer, James R Wyatt**, employed by **Ajax Metal Corporation, proposed in 1915** to make V – shaped channel in a vertical plane below the hearth.
- **The magnetic coupling is better than Direct Core Induction Type Furnace, therefore leakage reactance is comparatively low and p.f. is high.**

- Since it is a Vertical Core Type Furnace, the tendency of the currents **to interrupt the secondary circuit due to Pinch Effect** is avoided due to weight of the charge in the main body of the crucible.
- The circulation of the molten metal is kept up round the Vee portion by convection currents and by the electromagnetic forces between currents in the two halves of the Vee.
- As the furnace is having a narrow Vee shape at the bottom, therefore tendency of the molten metal will be to accumulate at the bottom and even a small amount of charge will keep the secondary completed. Hence the chances of discontinuity of the circuit are less. For this reason, the Ajax – Wyatt Furnace is useful for continuous operation.
- **The power factor of the circuit is of the order of 0.8 to 0.83 pf, and it can be operated at power frequency.**
- **This furnace is used for melting non – ferrous metals such as brass, zinc and tin.**

AJAX – WYATT FURNACE





MERITS OF AJAX - WYATT FURNACE:

1. Accurate control of temperature.
2. Uniform Castings.
3. Absence of Crucibles.
4. Consistent performance and simple control.
5. No combustion gases, thus eliminating the most common source of metal contamination.
6. Highly efficient heat, low running costs and improved performance.
7. Comparatively high power factor (0.8 – 0.85) with normal supply frequency since primary and secondary are both on the same central core.

INDIRECT CORE TYPE INDUCTION FURNACE

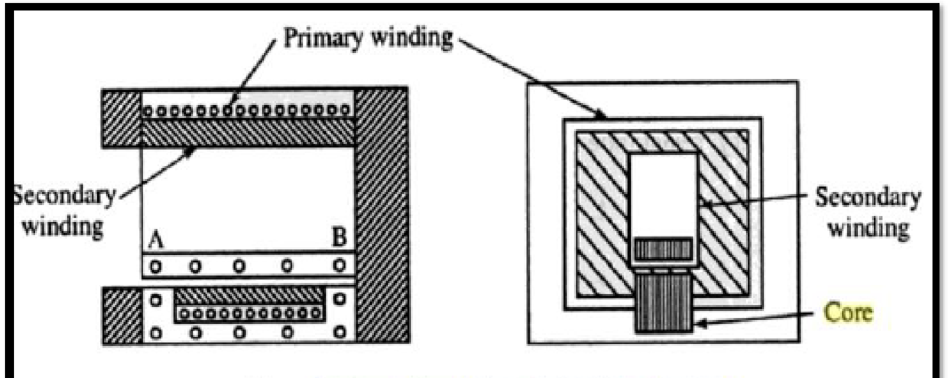


Fig. Indirect Core Type Induction Furnace.

- In this furnace, a suitable element is heated by induction which, in turn, transfers the heat to the charge by radiation.
- The secondary consists of a metal container which forms the walls of the furnace proper. The primary winding is magnetically coupled to this secondary by an iron core.
- When primary winding is connected to a.c. supply, secondary current is induced in the metal container by transformer action which heats up the container. The metal container transfers this heat to the charge.
- A special advantage of this furnace is that its temperature can be automatically controlled without the use of an external equipment.
- The part AB of the magnetic circuit situated inside the oven chamber consists of a special alloy which loses its magnetic properties at a particular temperature but regains them when cooled back to the same temperature. As soon as the chamber attains the critical temperature, reluctance of the magnetic circuit increases manifold thereby cutting off the heat supply. The bar AB is detachable and can be replaced by other bars (of different alloys) having different critical temperatures (400 ^{0}C and 1000 ^{0}C)

APPLICATIONS of INDUCTION HEATING

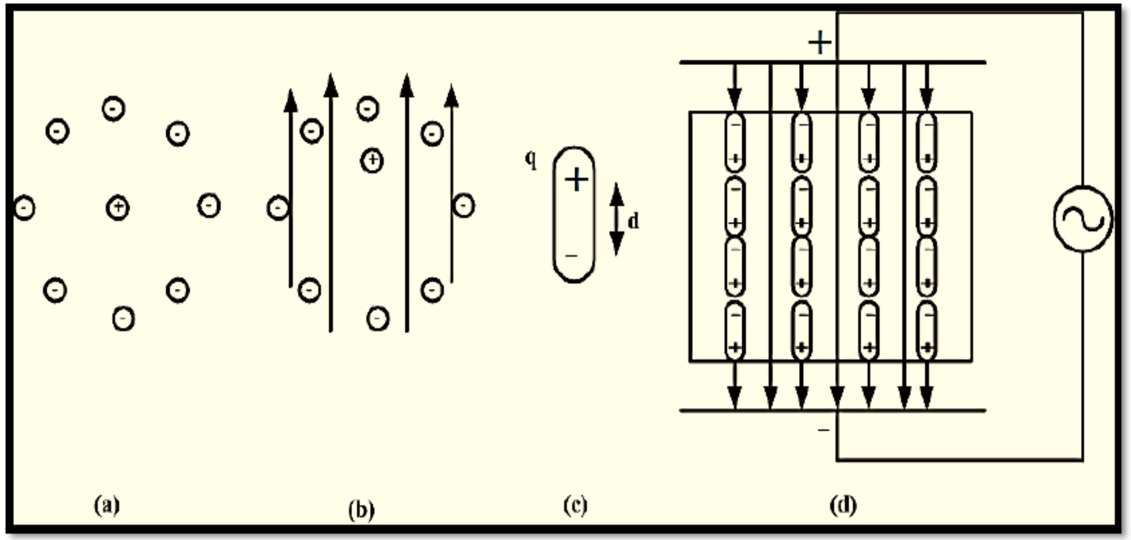
- The material of the work piece may be a metal such as steel, copper, aluminium or brass or it can be a semiconductor such as carbon, graphite or silicon carbide. To heat non-conductive materials such as plastics or glass, induction can heat an electrically-conductive susceptor, typically graphite, which then transfers the heat to the non-conducting material.
- Induction heating is used in processes where temperatures are as low as 100 °C (212 °F) and as high as 3000 °C (5432 °F).
- Induction heating is used in domestic and commercial cooking, and in many industrial applications such as melting, heat treating, preheating for welding, brazing, soldering, curing, sealing, shrink fitting in industry, and in research and development.

Comparison Between High Frequency And Power Frequency Furnaces

S. No.	High Frequency	Power frequency
1	Frequency converter is necessary	Not required.
2	More energy required i.e, 20% to 30% for same rating.	Less energy required.
3	Maintenance cost is more	Less
4	Less turbulence and stirring effect	More
5	Large scrap melts with more oxidation loss.	Large scrap melts with less oxidation loss.
6	No special starting procedure is required	Special starting procedure is required.

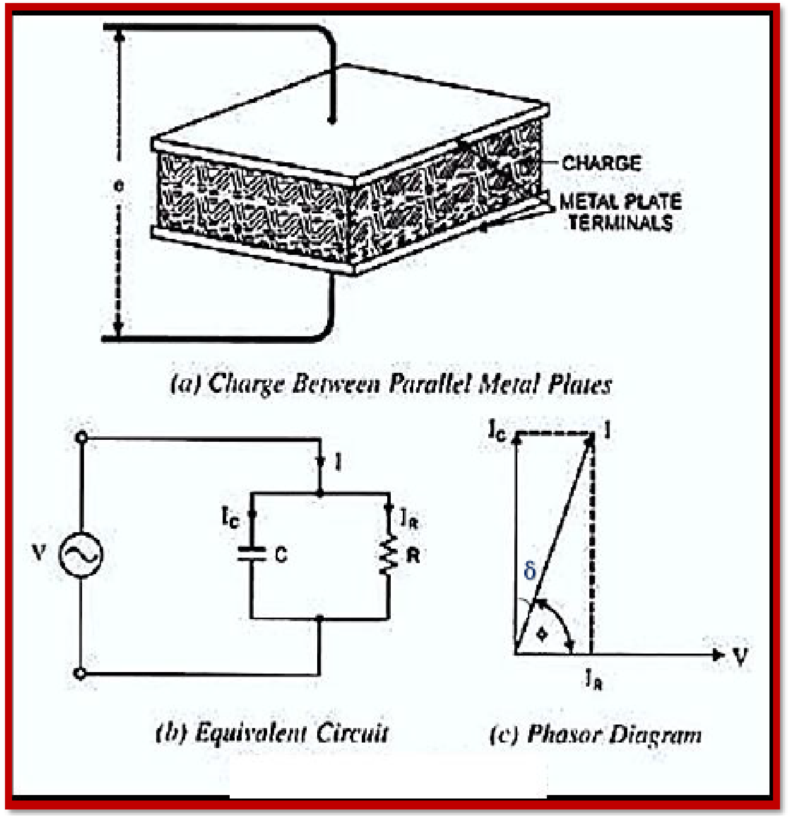
DIELECTRIC HEATING

- When an insulating material is subjected to an alternating electric field, the atoms get stressed and due to their interatomic friction, heat is produced. This heat loss is known as dielectric loss.
- When materials containing polar molecules having an electrical dipole moment is subjected to oscillating electric field, they will align themselves in rapidly oscillating electric field (these molecules rotate continuously by aligning with oscillating electric field). This is called **dipole rotation or dipolar polarization**. Rotating molecules push, pull, and collide with other molecules (through electrical forces), distributing the energy to adjacent molecules and atoms in the material. Once distributed, this energy appears as heat.



Dielectric heating (also known as electronic heating, RF heating and high frequency heating) involves the heating of electrically insulating materials by dielectric loss. A changing electric field across the material causes energy to be dissipated as the molecules attempt to line up with the continuously changing electric field.

All dielectric / insulating materials can be considered to be imperfect capacitor and can be represented by a parallel combination of a resistor ***R*** and a capacitor ***C.***



- The dielectric loss is directly proportional to the frequency of ac supply given to the two plates of the capacitor.
- In dielectric heating the heat is produced within the material itself. Because heat generation is uniform, the dielectric material is heated uniformly. This is the important property of dielectric heating.

$$Dielectric\ Loss\ (P) = \frac{V^2}{R}$$

$$From\ the\ phasor\ diagram\ \tan\delta = \frac{I_R}{I_C} = \frac{V/R}{V\omega C}$$

$$\frac{V}{R} = V\omega C \tan\delta$$

$$\frac{1}{R} = \omega C \tan\delta$$

$$\therefore\ P = \frac{V^2}{R} = V^2\omega C \tan\delta \quad (\tan\delta = dielectric\ loss\ tangent\ /\ dissipation\ \ factor)$$

$$Normally\ \delta\ is\ small$$

$$\therefore\ P = V^2\omega C\delta\ \ watt$$

Where **δ** is in radian and is known as the loss angle. It is an indication of the state of the dielectric whether it is healthy or unhealthy. The higher the value of **δ,** the less healthy is the state of the dielectric material.

$$Current\ through\ the\ capacitor, I_C = \frac{V}{X_C} = \frac{V}{1/2\pi fC} = V2\pi fC\ Amps$$

$$where\ C\ is\ in\ farads\ and\ V\ is\ in\ volts$$

$$The\ current\ drawn\ from\ sup\ ply,$$

$$I \cong I_C \cong 2\pi fCV\ \ Amps$$

$$Power\ produced, P = VI\cos\phi = V \times 2\pi fCV \times \cos\phi\ Watts$$

$$= 2\pi fCV^2 \times \cos\phi\ Watts$$

$$The\ capaci\tan ce\ of\ a\ parallel\ plate\ capacitor\ is\ given\ as$$

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

$$where\ \varepsilon_0\ is\ the\ permittivity\ cons\tan t$$

$$\varepsilon_r = relative\ permittivity\ of\ the\ medium$$

$$A = Area\ of\ the\ plate\ (m^2)$$

$$d = thickness\ of\ the\ medium\ (m)$$

$$\text{Therefore, dielectric loss, } P = V^2 2\pi f \times \frac{\varepsilon_0 \varepsilon_r A \delta}{d}$$

$$\text{So,} \qquad P \propto V^2 \text{ and } P \propto f$$

- By varying one of these two quantities, the rate of dielectric heating can be varied. The insulation problem limits the voltage to be used; hence to achieve more heat, high frequency is used. However, there is a limit also, on the high frequency, imposed by cost involved in getting a circuit for obtaining very high frequencies and other difficulties.
- The product **$\varepsilon_r \delta$** is known as the loss factor. The **loss tangent tan δ** is a measure of how a material dissipates electrical energy as heat.
- Usual frequency used for dielectric heating is in the range of 1 to 30 MHz. Though higher frequencies between 50 – 200 MHz are also used but these power supplies are of low output.

APPLICATIONS OF DIELETRIC HEATING:

- The fact that water heats at a much more rapid rate than any other material when subjected to high frequency field, dielectric heating is most conveniently used for moisture removal especially when the moisture is disposed uniformally deep into the material and no other conventional heating method is available for its removal.
- Dielectric heating is also used for
  1. Heating thin films such as lacquers and paints applied to metallic surfaces,
  2. Preparation of thermo – plastic resins.
  3. Heat – sealing of plastic sheets,
  4. Bonding of laminated wood,
  5. Drying of textiles,
  6. Dehydration of food and tobacco,
  7. Sterilization of cereals, etc.

MERITS OF DIELETRIC HEATING:

1. If the material to be heated is homogeneous, and the alternating (or varying) electric field is uniform, heat is developed uniformly and simultaneously throughout the entire mass of the charge.

2. As materials heated by this process are non-conducting, so by other methods heat cannot be conducted to inside so easily.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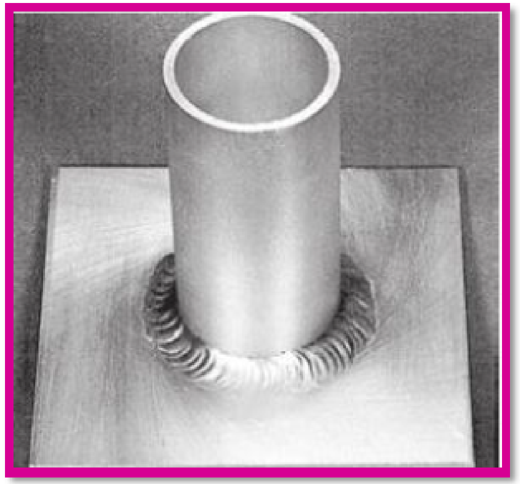
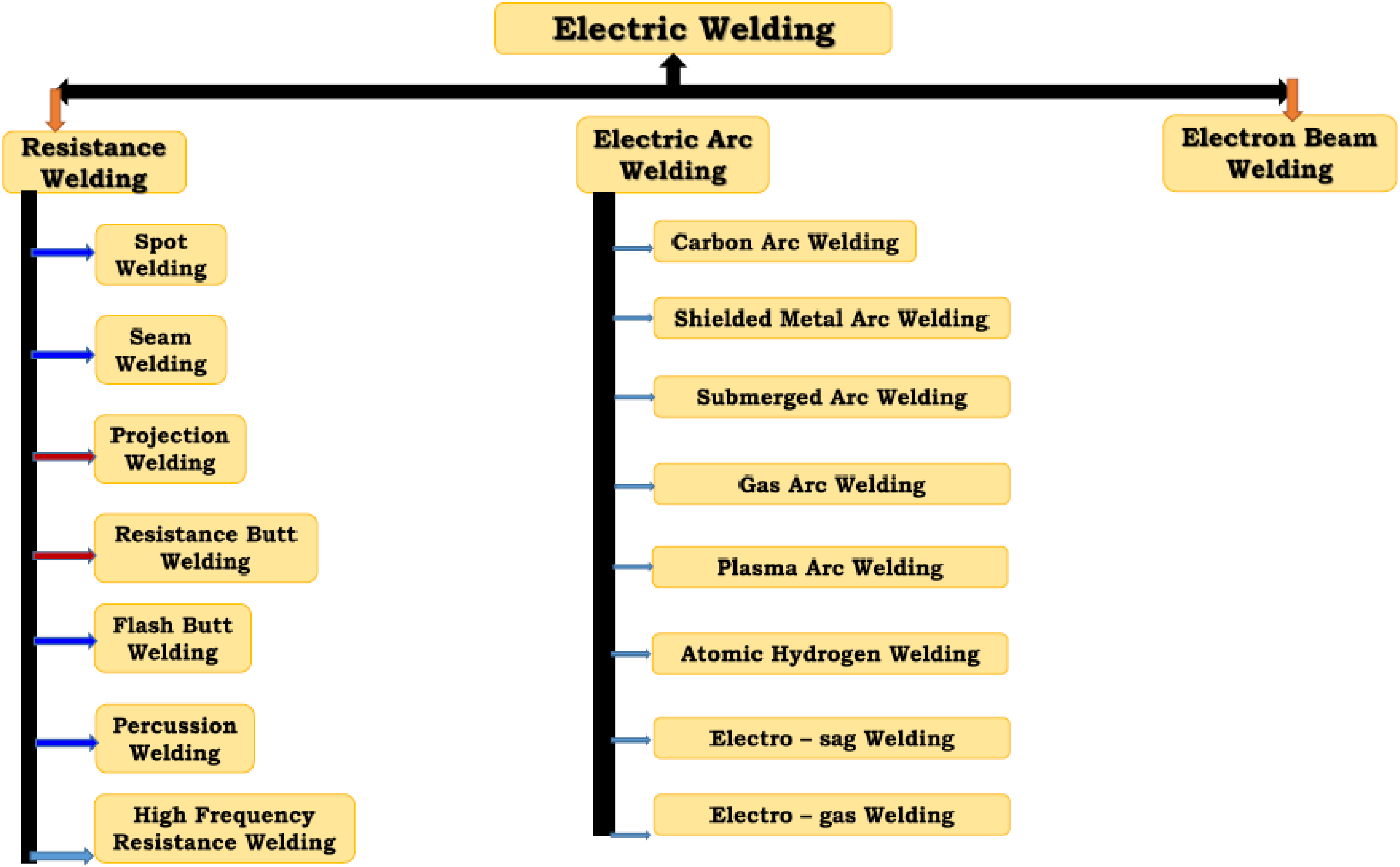
ELECTRIC WELDING

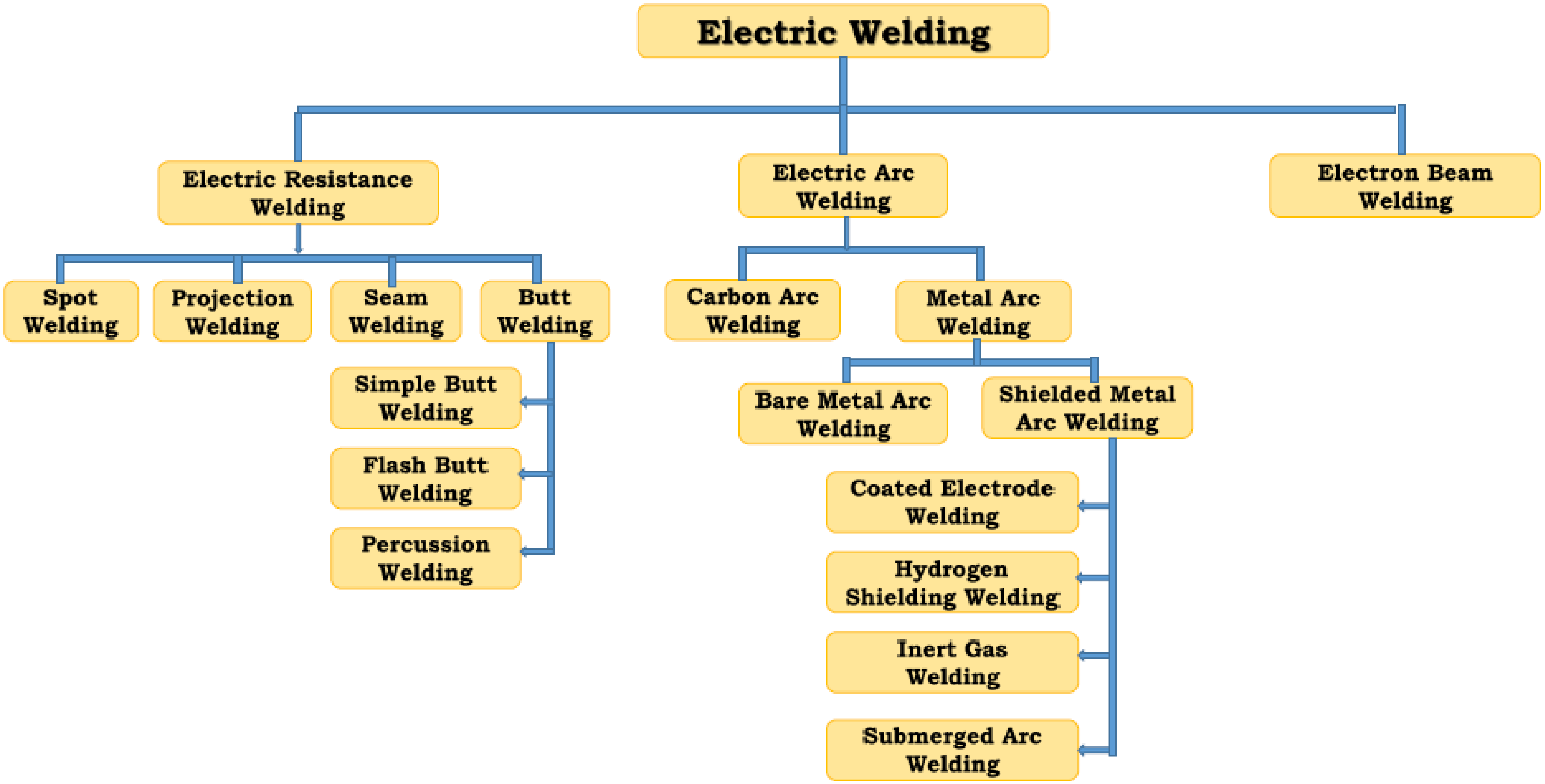
- Welding is defined as **“a joining process that produces coalescence of materials (the fusion or growing together of the grain structure of the materials being welded) by heating them to the welding temperature, with or without the application of pressure, or by the application of pressure alone, and with or without the use of filler material”**.
- Alternatively defined, **Welding is the joining together of two pieces of metal by heating to a temperature high enough to cause softening or melting, with or without the application of pressure, and with or without the use of filler material.**
- Any filler material used has either a melting point approximately the same as metals being joined or a melting point that is below these metals but above 800 degrees Fahrenheit.



Welding is a process in *which materials of the same fundamental type or class are brought together and caused to join (and become one) through the formation of primary (and, occasionally, secondary) chemical bonds under the combined action of heat and pressure.*

Welding is the result of the combined action of heat and pressure.


Electric Welding
Resistance Welding
Electric Arc Welding
Electron Beam Welding
Spot Welding
Seam Welding
Projection Welding
Resistance Butt Welding
Flash Butt Welding
Percussion Welding
High Frequency Resistance Welding
Carbon Arc Welding
Shielded Metal Arc Welding
Submerged Arc Welding
Gas Arc Welding
Plasma Arc Welding
Atomic Hydrogen Welding
Electro – sag Welding
Electro – gas Welding


Electric Welding
Electric Resistance Welding
Electric Arc Welding
Electron Beam Welding
Spot Welding
Projection Welding
Seam Welding
Butt Welding
Carbon Arc Welding
Metal Arc Welding
Simple Butt Welding
Flash Butt Welding
Percussion Welding
Bare Metal Arc Welding
Shielded Metal Arc Welding
Coated Electrode Welding
Hydrogen Shielding Welding
Inert Gas Welding
Submerged Arc Welding

Resistance Welding

- Resistance welding is a process in which fusion between the **parts' surfaces occurs** as a result of the heat produced by the resistance between the parts' contacting surfaces.
- The welding current required to make a resistance weld must be at a very low voltage but at a high amperage. Pressure is constantly applied while the current is applied to ensure a continuous electrical circuit and to forge the heated parts together.
- By definition, a weld is a localized coalescence **(Fastening two pieces of metal together by softening with heat and applying pressure)** of metal heated to a suitable temperature.
- The rate at which the heat is generated is given by:

$$W = I^2 R$$

where W = Electrical power in watts

I = Current in Amps

R = Resistance in Ohms

- If the power is applied over a time interval of t seconds, the heat energy developed in the resistance is:

$$Q = I^2 R t$$

where Q = Watt – sec or Joules

SPOT WELDING

- In this process overlapping sheets are joined by local fusion at one or more spots, by the concentration of current flowing between two electrodes. This is the most widely used resistance welding process.

OR

In this process, the weld is produced by the heat obtained at the interface between the workpieces. This heat is due to the resistance to the flow of electric current through the workpieces, which are held together by pressure from the electrode.

- The size and shape of the formed welds are controlled somewhat by the size and contour of the electrodes. The welding time is controlled by a timer built into the machine or by a computer program.

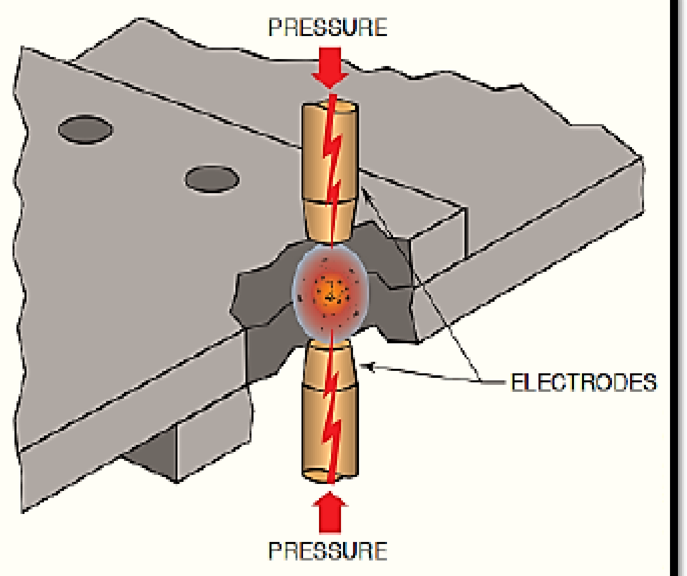


FIGURE : Heat resulting from resistance of the current through the metal held under pressure by the electrodes creates fusion of the two workpieces during spot welding.

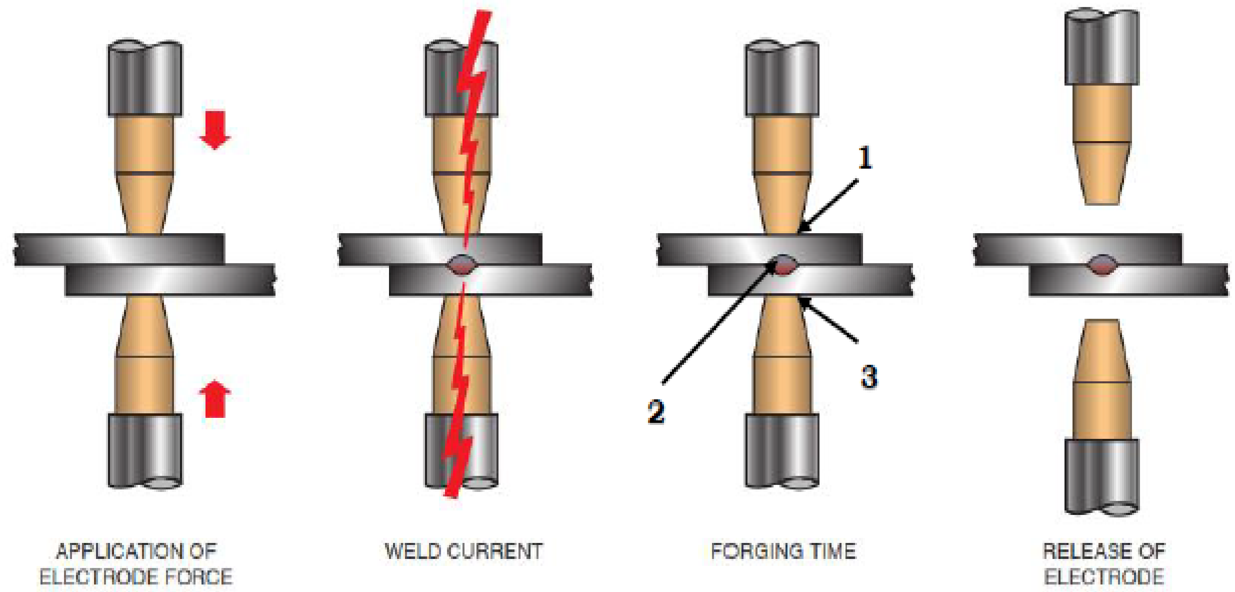
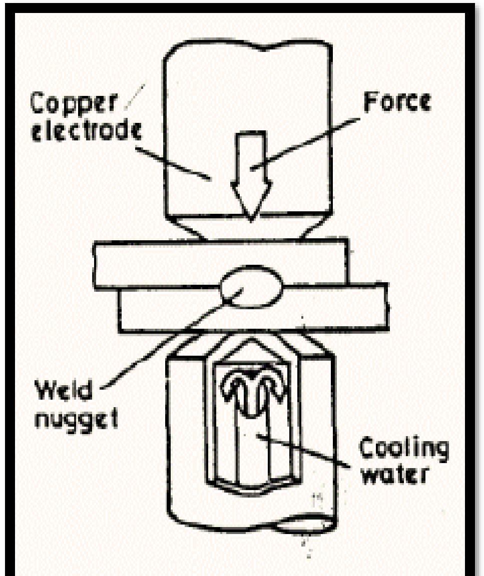


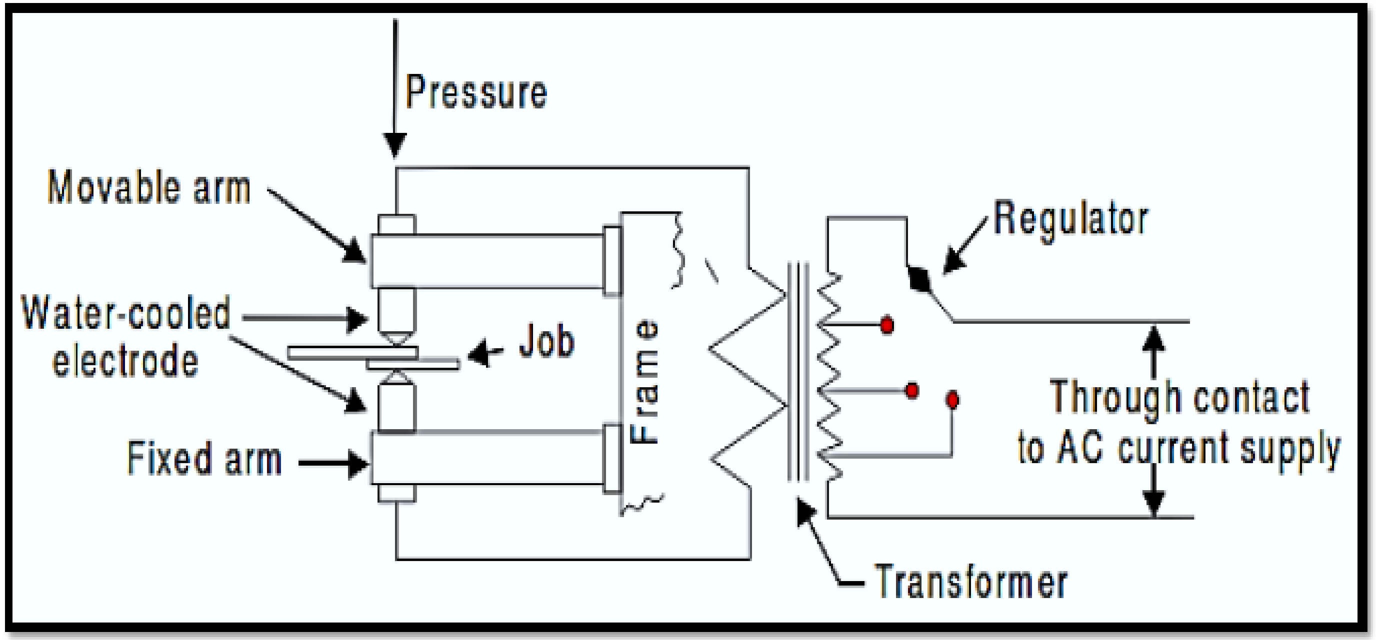
FIGURE Basic periods of spot welding.

- Heat generation at junctions at 1 and 3 will cause electrode sticking and melt through hole. As such heating of junctions 1 and 3 is to be avoided. This is achieved by taking following measures:

1. By water cooling the electrodes, junctions 1 and 3 are cooled.
2. Electrodes are made of materials (copper beryllium and copper tungsten) which have high electrical conductivity and high thermal conductivity so that heat developed at junctions 1 and 3 is minimum in the first instance. Secondly, whatever heat is developed is efficiently conducted away.



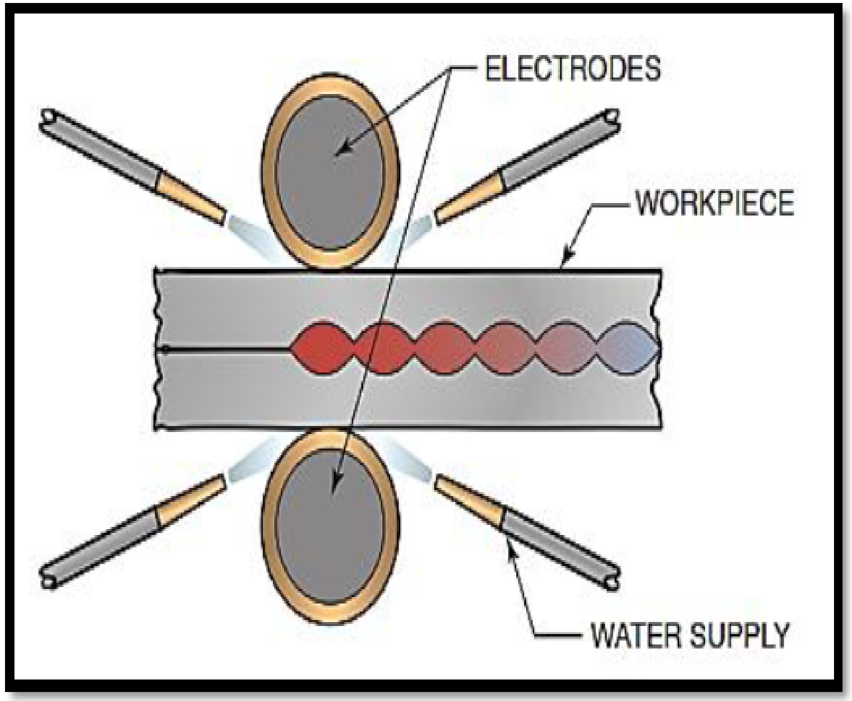
(b) Operation

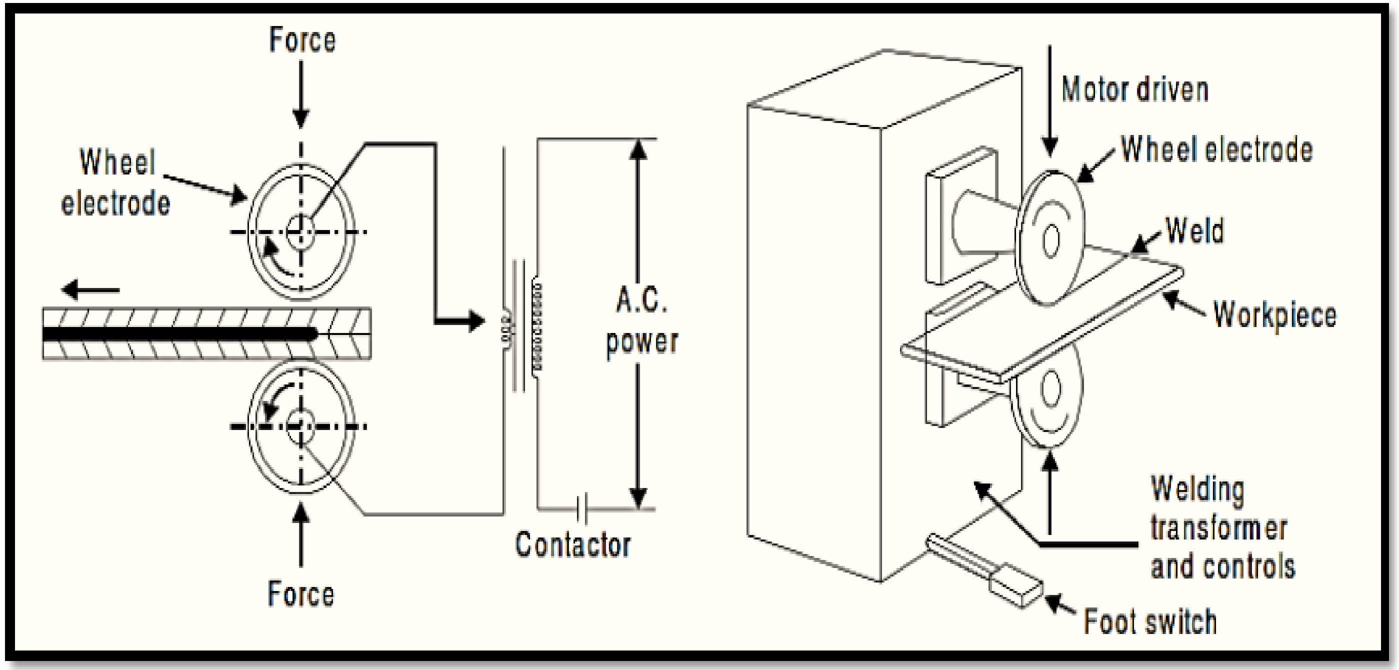


Applications: Spot welding is mainly used for lap welding of thin sheets particularly in the welding of automobile and refrigerator bodies, and high quality work in aircraft engines.

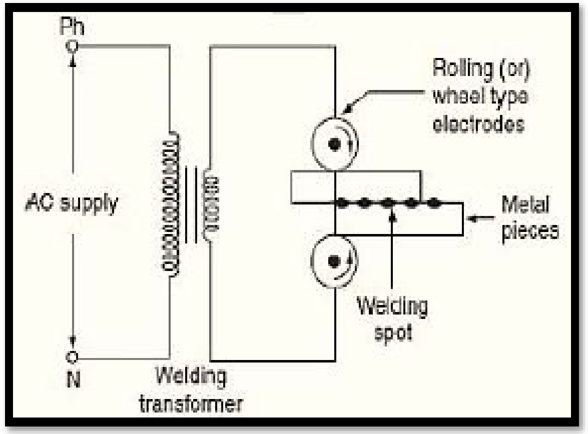
SEAM WELDING

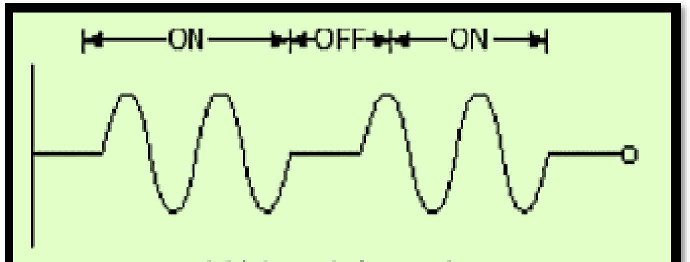
- Seam welding is similar in some ways to spot welding except that the spots are spaced so closely together that they actually overlap one another to make a continuous seam weld. Seam welding is accomplished by using roller-type electrodes in the form of wheels.
- In this welding process coalescence at the faying surfaces (**A faying surface is one of the surfaces that are in contact at a joint**) is produced by the heat obtained from the resistance to electric current (flow) through the work pieces held together under pressure by circular electrodes.
- Cooling is achieved by a constant stream of water directed to the electrode near the weld





- It is not satisfactory to make a continuous weld, for which the flow of continuous current build up high heat that causes burning and wrapping of the metal piece. To avoid this difficulty, an interrupter is provided on the circuit which turns on supply for a period sufficient to heat the welding point.
- The series of weld spots depends upon the number of welding current pulses. Magnitude of welding current depends upon the thickness of the sheets to be welded.





(a) Interrupted current

Applications

1. It is used for making leak proof joints in fuel tanks of automobiles.

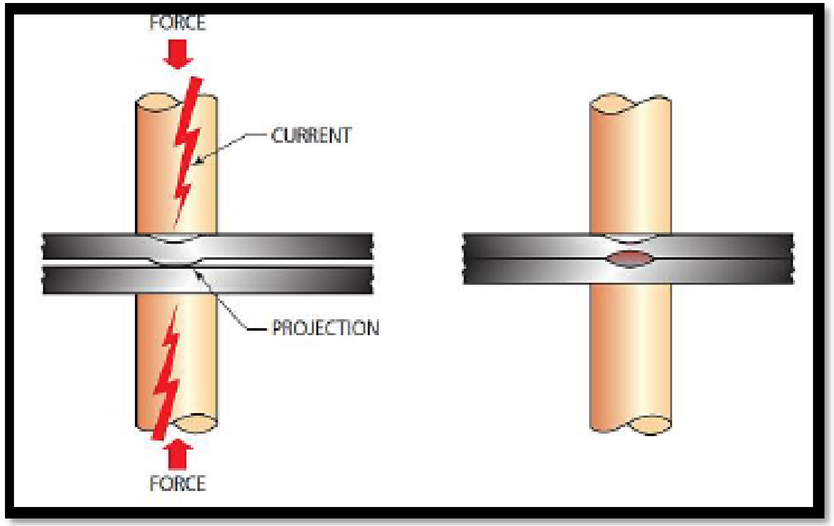
2. Except for copper and high copper alloys, most other metals can be seam welded.

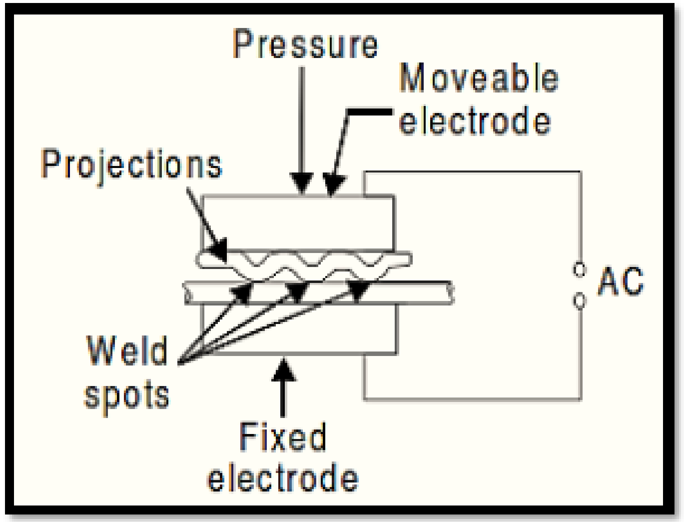
3. It is also used for making flange welds for use in watertight tanks.

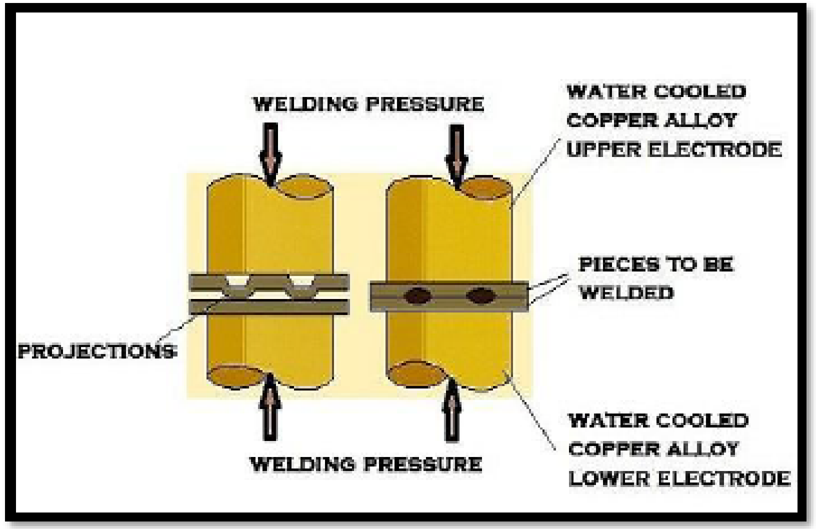
S No.	Weld spots/inch	On off time in cycle	No. of cycles/inch weld	Supply frequency	Time in sec/inch weld	Welding speed in inch/sec
1	10	5	50	50	1	1"/sec
2	10	5	50	100	$\frac{1}{2}$	2"/sec
3	5	$1\frac{1}{2}$	15/2	50	3/20	$\frac{20}{3}$" /sec
4	15	$1\frac{1}{2}$	45/2	50	9/20	$\frac{10}{3}$" / sec

PROJECTION WELDING

- This process is a resistance welding process in which **two or more than two spot welds are made simultaneously by making raised portions or projections on predetermined locations on one of the workpiece**. These projections act to localize the heat of the welding circuit.
- The pieces to be welded are held in position under pressure being maintained by electrodes.
- The **projections**—small, raised areas—can be any shape, such as round, oval, circular, oblong, or diamond. They can be formed by embossing, casting, stamping, or machining.
- The workpieces that have the projections and the other workpiece are placed between plain, large-area electrodes in the welding machine.

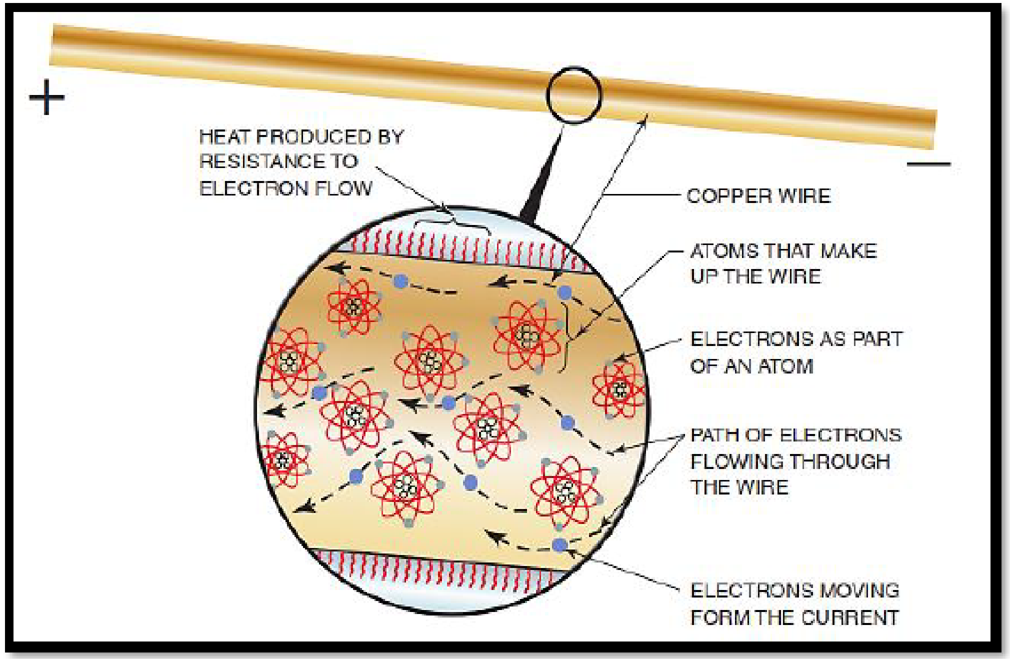


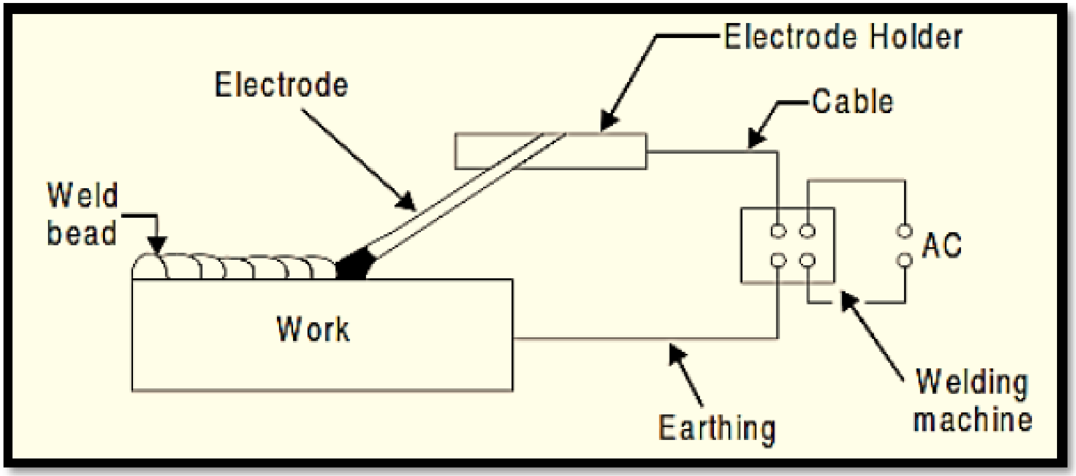




Applications: Steel plate, galvanized sheet steel, and stainless steels can be joined using projection welding.

ELECTRIC ARC WELDING



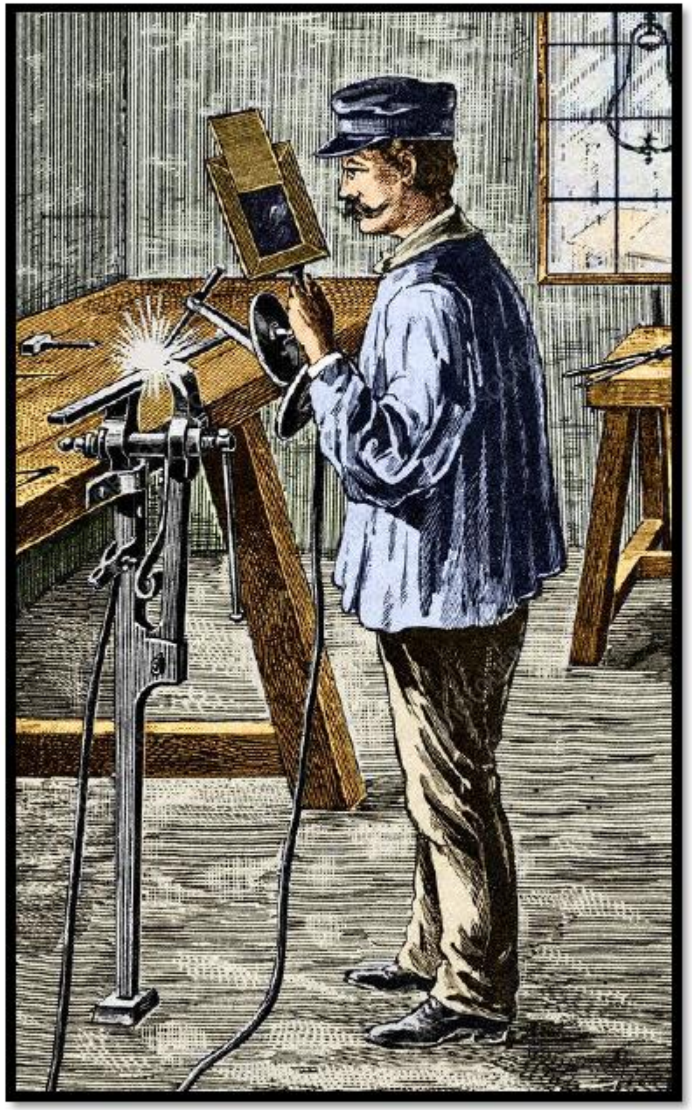


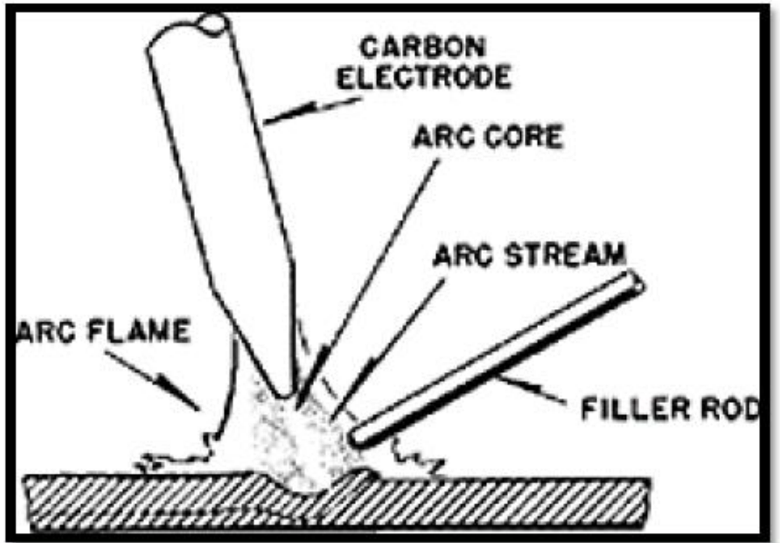
- **The process, in which an electric arc between an electrode and a workpiece or between two electrodes is utilized to weld base metals, is called an arc welding process.**

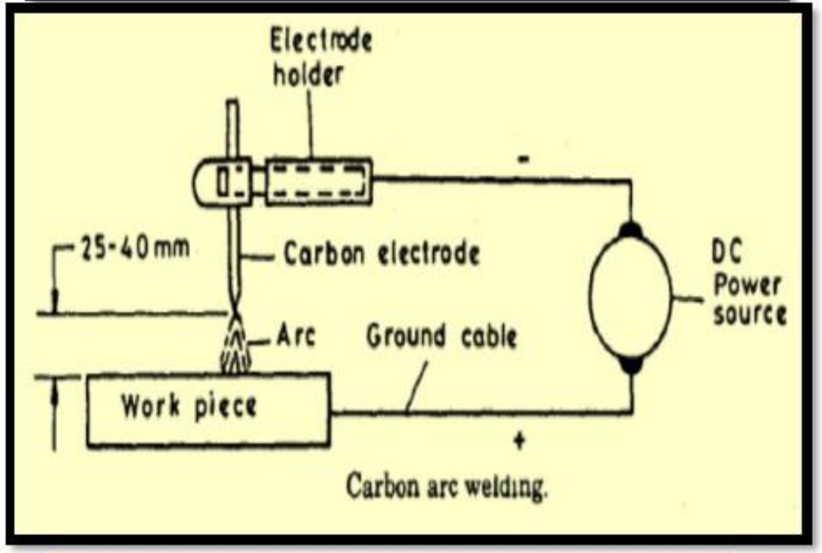
OR

- A welding process wherein heat required for welding or obtaining coalescence is produced with an electric arc with or without the application of pressure and with or without the use of filler material.
- **The arc in arc welding is created between an electrode and a workpiece or a weldment, each at different polarities. The arc itself consists of thermally emitted electrons and positive ions from this electrode and the workpiece. These electrons and positive ions are accelerated by the potential field (voltage) between the source (one electrode) and the work (the opposite charged electrode), and produce heat when they convert their kinetic energy by collision with the opposite charged element.**
- The electrode can be intended to be permanent, serving solely as a source of electrons or positive ions, or consumed, in which case it serves both as a source of energy for welding from these particles and as a filler to the weld joint.

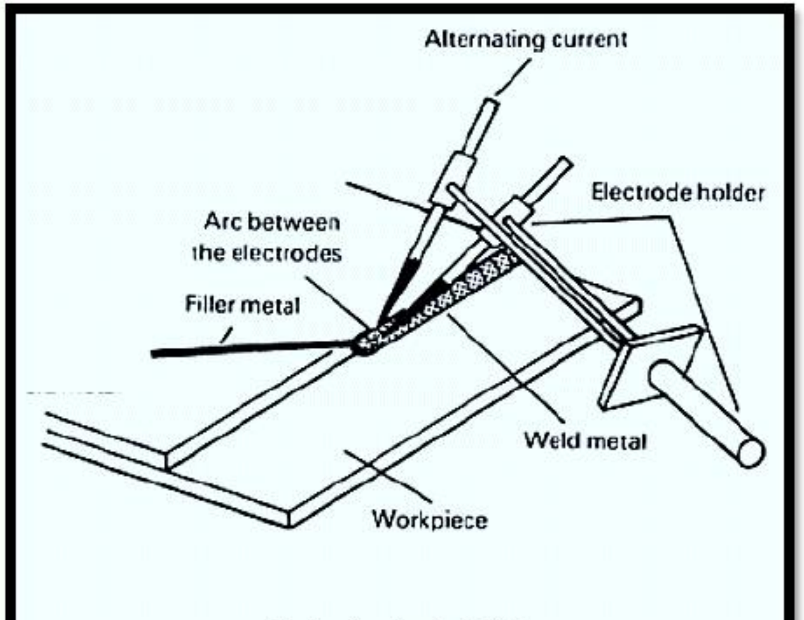
CARBON ARC WELDING







SINGLE ELECTRODE CAW



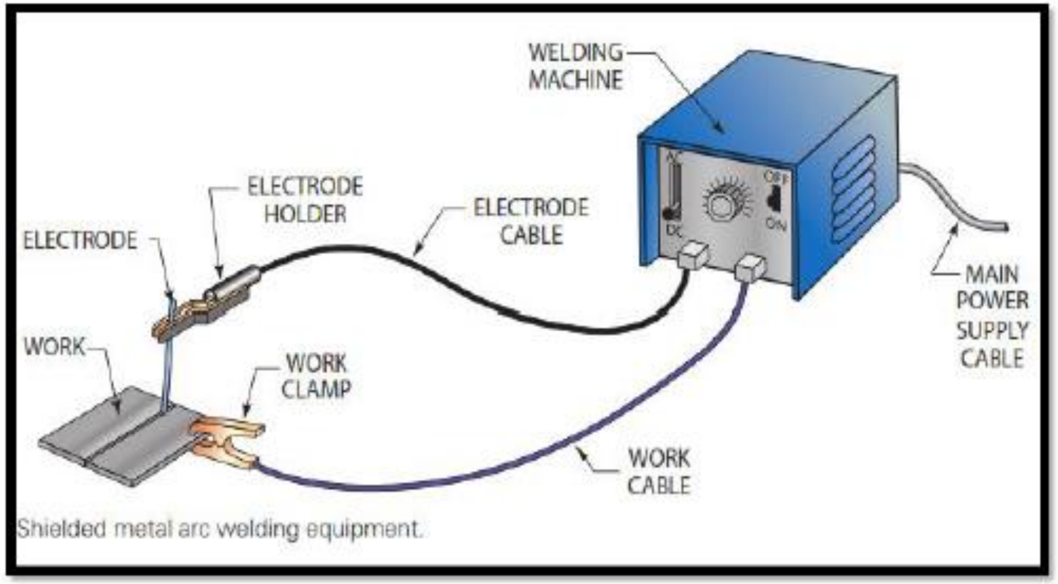
Twin-electrode CAW

CARBON ARC WELDING

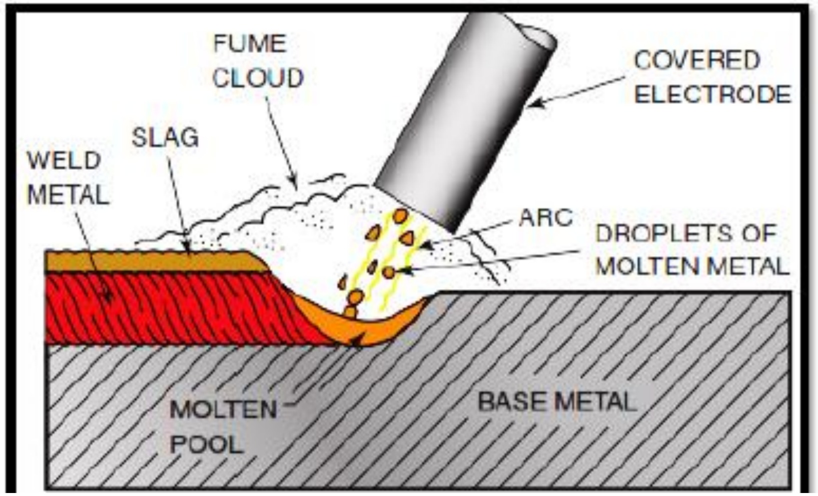
- **CARBON ARC WELDING (CAW) utilizes what is considered to be a nonconsumable electrode, made of carbon or graphite, to establish an arc between itself and either the workpiece or another carbon electrode.**
- **Normally, no shielding gas is used.**
- **SINGLE ELECTRODE CAW: In this case the power supply for releasing the heat is DC. The electrode always acts as cathode (negative). The arc is created between the electrode and the workpiece which always act as anode (+ve). The arc is struck by touching the electrode with the job momentarily and then taking away by appropriate distance (generally 10 to 15 mm apart). The arc is allowed to impinge on the surface to be welded to form a pool of molten metal. The holder is steadily moved to complete the welding process.**
- **TWIN ELECTRODE CAW: The twin-electrode arrangement usually operates with alternating current (ac), generally with small ac power supplies. The arc is maintained between two carbon electrodes held in a special holder. The electric torch consists of two carbon electrodes that can be adjusted by means of a thumb – operated mechanism located on the handle of the electrode holder. The electrodes can be moved closer or further apart, making the arc of desired length.**

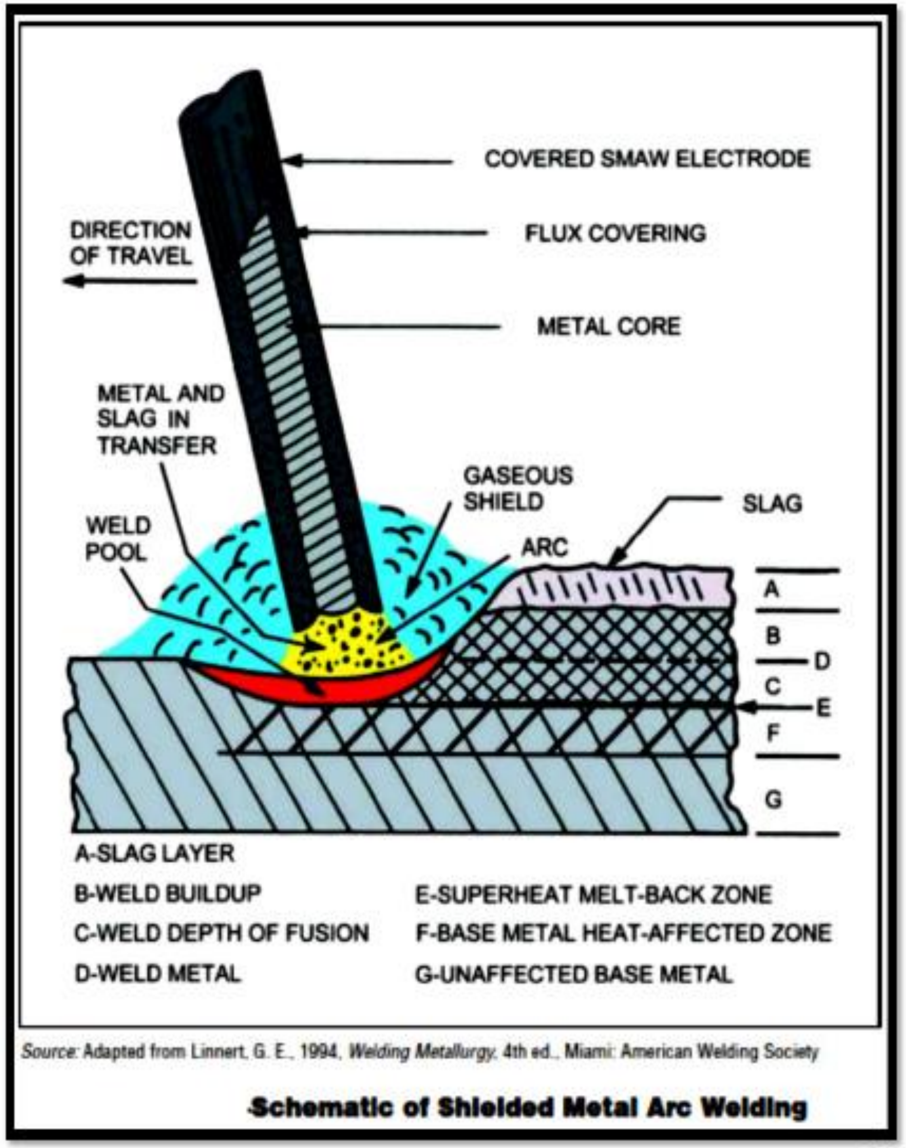
Applications: Used for welding steel, nickel, aluminium, copper and their alloys. It is also employed for brazing, pre – heating and post – heating of the welded joints.

SHIELDED METAL ARC WELDING (SMAW)



Shielded metal arc welding equipment.





Source: Adapted from Linnert, G. E., 1994, *Welding Metallurgy*, 4th ed., Miami: American Welding Society

Schematic of Shielded Metal Arc Welding

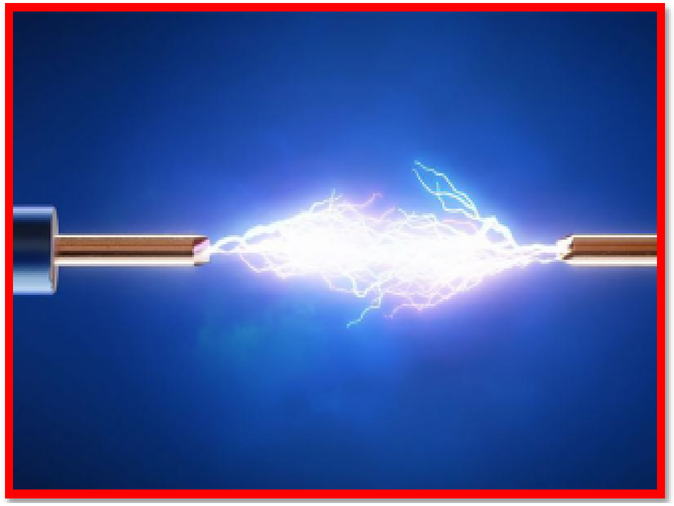
- **Shielded** refers to its ability to displace the air surrounding the weld to avoid the harmful effects of the gases in air; **metal** denotes the core of the electrode, which is a conducting rod that contributes a substantial portion of liquid metal to the weld pool; **arc** refers to the plasma discharge that converts the electrical energy into heat. The term **welding,** in this case, denotes that the metals are joined by fusion
- **The shielded metal arc welding (SMAW) process is also known as the stick welding process.**
- **Shielded metal arc welding (SMAW) uses a consumable stick electrode that conducts the welding current from the electrode holder to the work, and as the arc melts the end of the electrode away, it becomes part of the weld metal.**
- **Stick electrodes are available in lengths of 12 in., 14-in., and 18 in. (300 mm, 350 mm, and 450 mm).**
- **The welding arc vaporizes the solid flux that covers the electrode so that it forms an expanding gaseous cloud that serves many functions like protect the molten weld metal; arc stability etc.**
- **SMAW is a widely used welding process because of its low cost, flexibility, portability, and versatility. The machine and the electrodes are low in cost.**

Applications: Extensively used in the fabrication of ships, bridges, pressure vessels, and structurals; however it is used in its manual mode only.

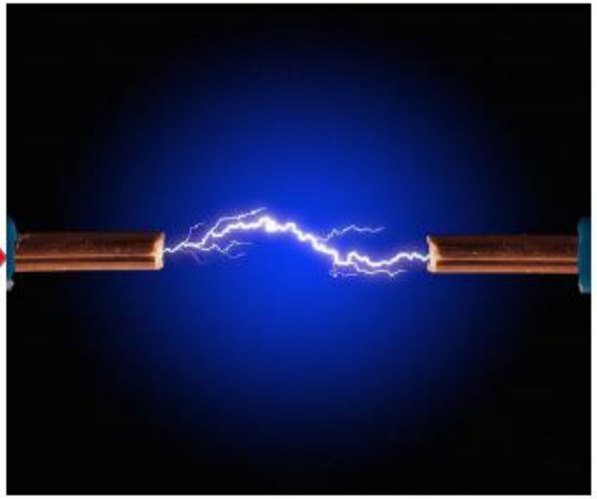
ELECTRIC ARC HEATING

- An arc between two electrodes can be initiated by ionization (electrical current ionizing gases in the air) and is accompanied by visible light, as the current through the electrodes is increased. An electric arc is the form of electric discharge with the highest current density, and maximum temperature.

- The breakdown voltage of the electrode gap is a function of the pressure and type of gas surrounding the electrodes.

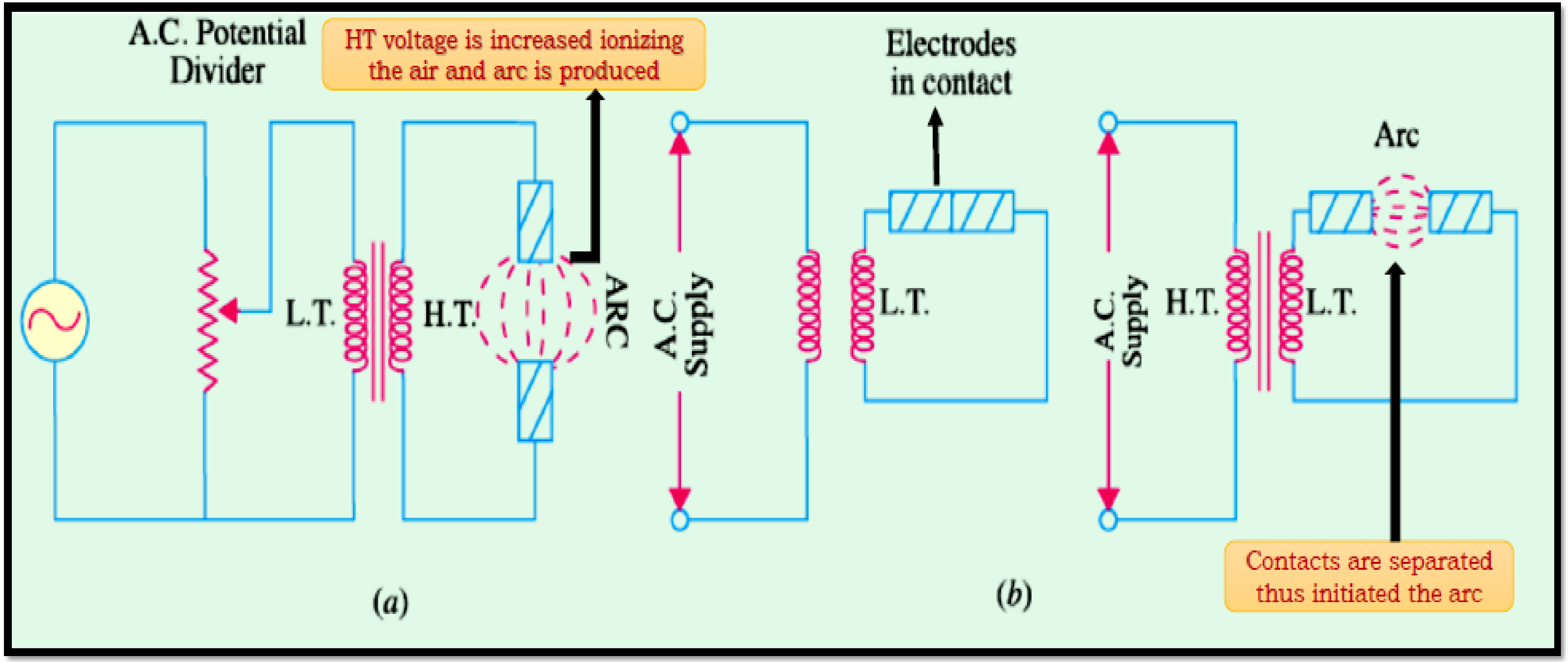


Electric Arc

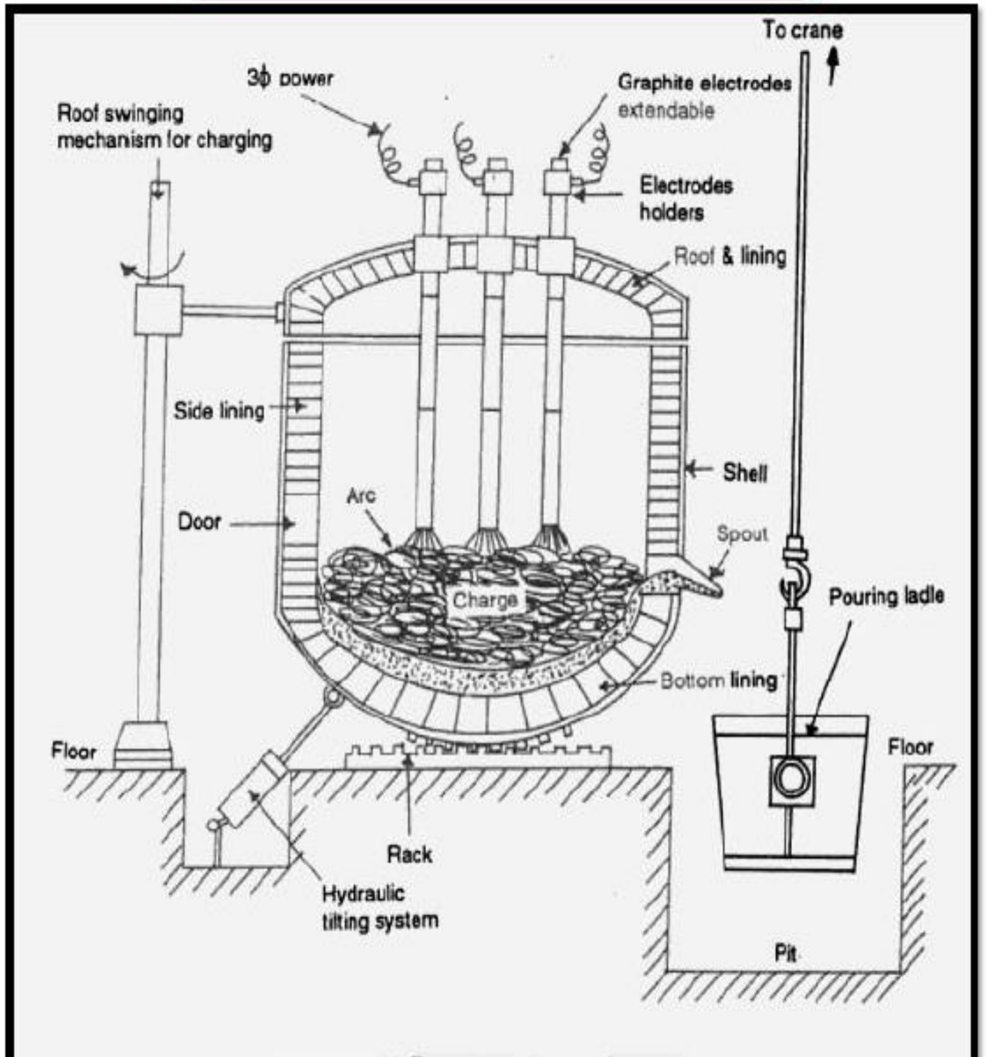


Electrical resistance along the continuous electric arc creates heat, which dissociates more gas molecules and ionizes the resulting atoms (where degree of ionization is determined by temperature)

- The electric arc temperature reaches around **3000°C - 3500°C (≅ 5000°F - 6000°F),** thus causing the lower sections of the electrodes glow incandescently when in operation.



Direct Arc Furnace



3ϕ Direct arc electric furnace

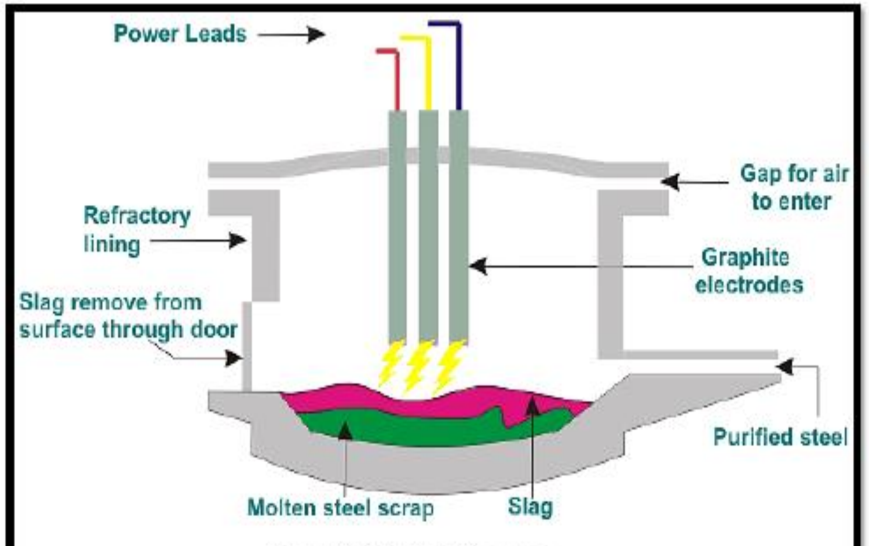
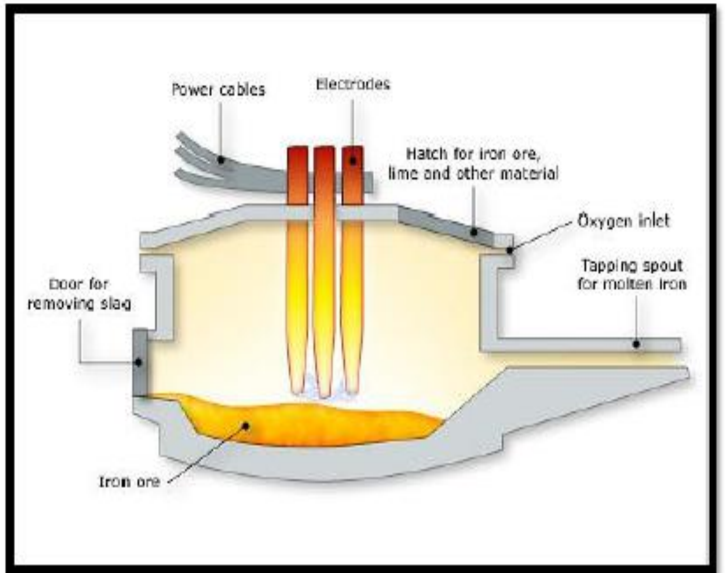
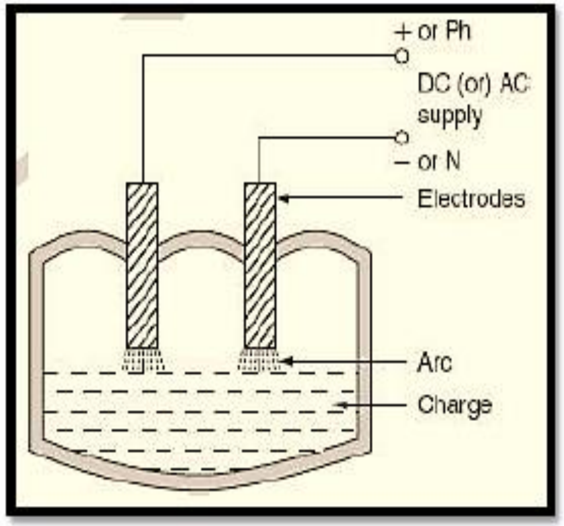
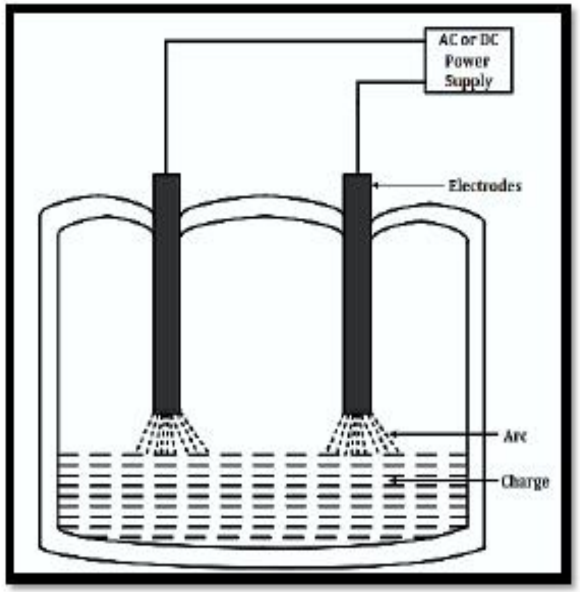
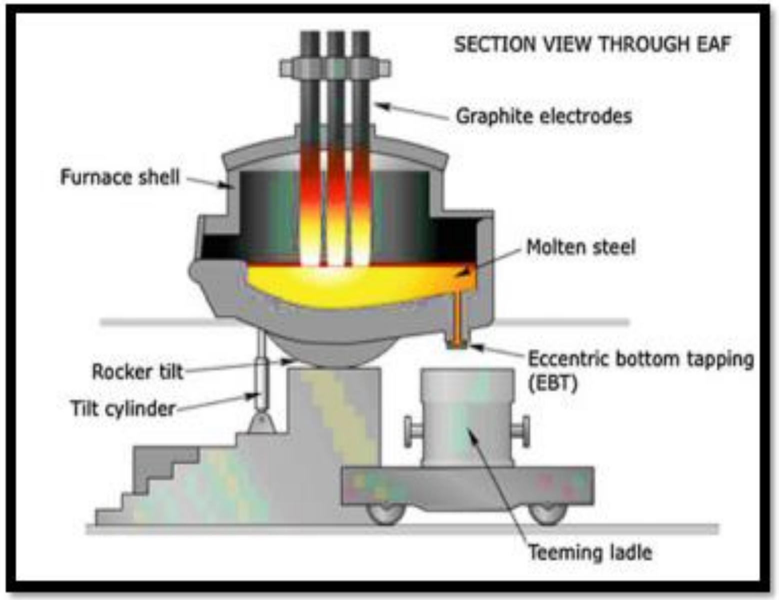


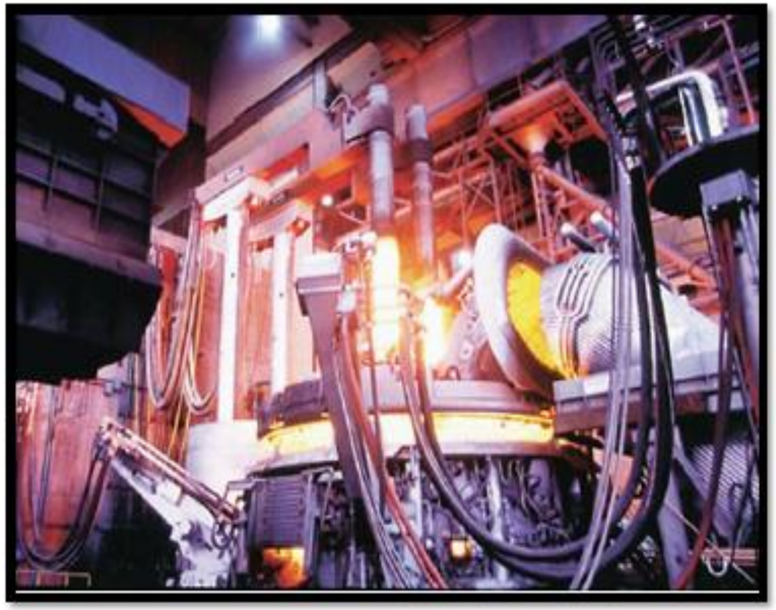
Figure 2. Electric Furnace











In Direct Arc Heating, the arc is established between the electrodes and the charge (or workpiece). As the arc is in direct contact with the charge (or workpiece) and heat produced is directly conducted to the charge which the charge absorbs. Hence, it is known as direct arc furnace.

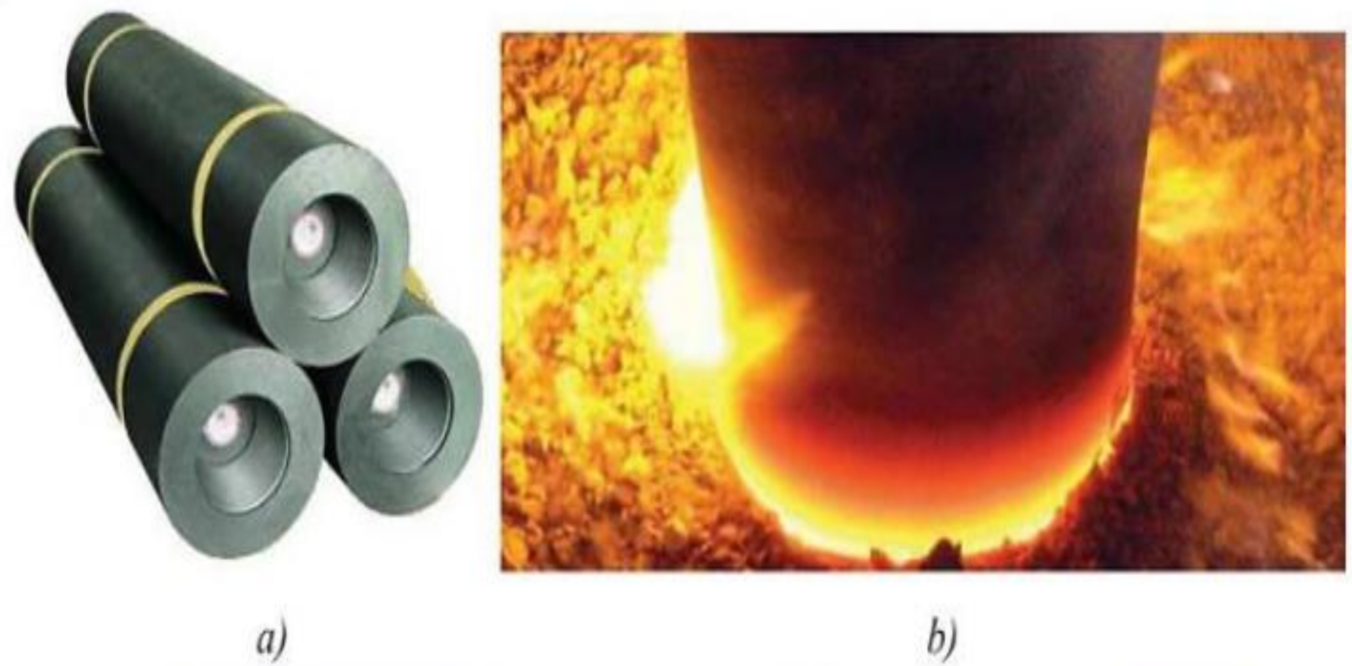
- **As in direct arc furnace, the arc is directly in contact with the charge, therefore, maximum heating or very high temperature can be obtained.**
- **The electrodes used in arc furnaces are of three types namely**
  - **a. Carbon electrodes,**
  - **b. Graphite electrodes, and**
  - **c. Self-baking electrodes.**
- Material of the electrodes namely **carbon and graphite** has been selected on account of their **electrical conductivity**, **insolubility**, **infusibility**, **chemical inertness**, **mechanical strength and resistance to thermal shock**. **The size of these electrodes may be 18 cm to 27 cm in diameter**. With graphite or carbon electrode, the temperature obtainable from the arc is between 3,000 °C and 3,500 °C.

- The trend is toward the general use of **graphite electrodes.** More than **95%** of the world electric steel production is produced using **graphite electrodes.** Only a very small part of steel is produced in electric arc furnaces using carbon electrodes without **graphitization**.

- The **average electrical resistance** of the graphite electrodes is **4 to 5 times higher**, and the **current density** is upto **2.5 times higher**, **so a high concentration of power can be achieved**, which is advantageous in terms of good efficiency and high temperature.

- Graphite electrodes have a lower weight, so they are easily to handle and break less often in comparison with carbon electrodes, which reduces the electrodes consumption in steel production.

- Graphite has **high thermal conductivity** and is very **resistant to heat and impact.**



Graphite electrodes for steel production (a) and electrode location in furnace (b)

- Graphite begins to **oxidise at about 600 °C** where as **carbon at about 400 °C.**

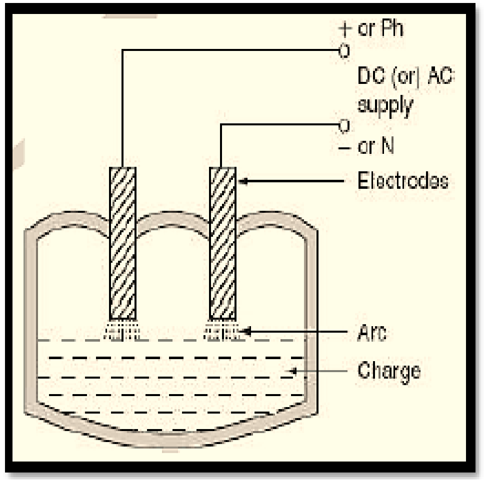
- **Carbon electrodes** are used with small furnaces for manufacture of ferro-alloys, aluminium, calcium carbide, phosphorous etc.
- **Self-baking electrodes** are employed in ferro-alloys and electrochemical furnaces and in electrolytic production of aluminium.

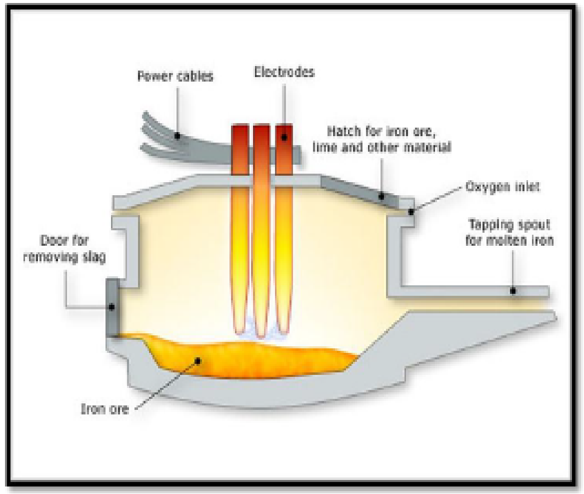
The salient features of carbon and graphite electrodes are:

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 ^{0}C where as carbon at 400 ^{0}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 2.3to 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, graphite electrodes are outstanding choice.

Note: Students are suggested to read the constructional features of Arc Furnaces **(both Direct Arc Furnace and Indirect Arc Furnace)** from their own efforts (or side).





Construction and Operating Principle: In a direct arc furnace, charge acts as one of the electrodes and the charge is heated by producing arc between the electrodes and the charge. Since in a direct arc furnace, the arc is in direct contact with the charge and heat is also produced by flow of current through the charge itself, the charge can be, therefore, heated to highest temperature.

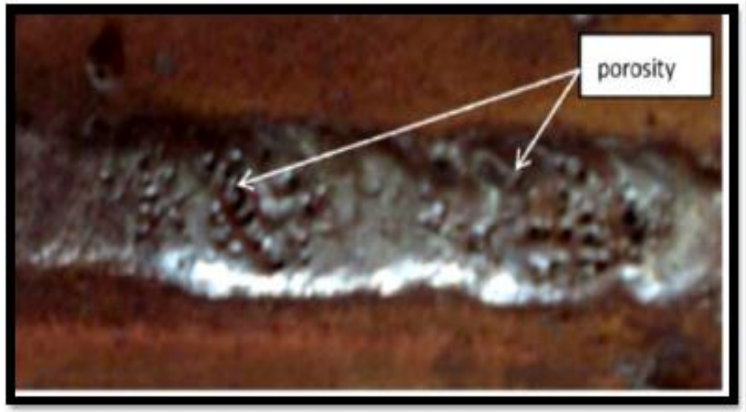
In case of a single phase arc furnace two electrodes are taken vertically downward through the roof of the furnace to the surface of the charge and in a 3- phase furnace three electrodes put at the corners of an **equilateral triangle**, project on the charge through the roof and three arcs are formed. **The current passing through the charge develops electromagnetic field (develops electromagnetic force) and necessary stirring action is automatically obtained by it**. Thus uniform heating is obtained.

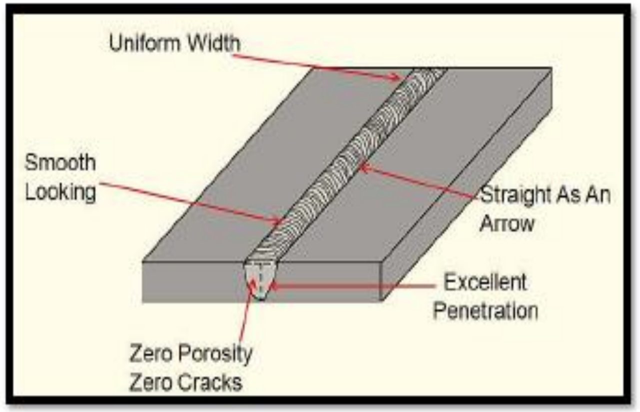
It is commonly used for production of steel. The usually size of such a furnace is between **5 and 10 tonnes**, though **50 and 100 tonne arc furnaces** have also been developed.

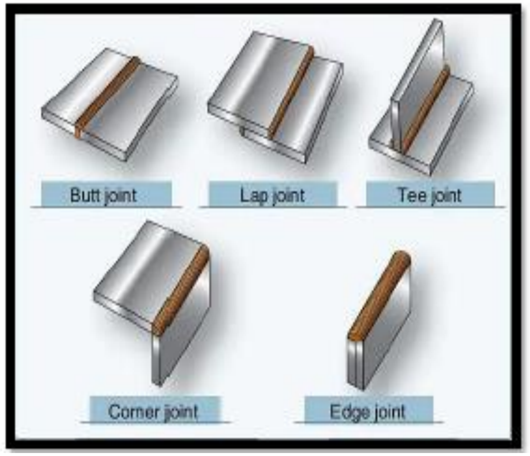
REQUIREMENTS OF A GOOD WELD

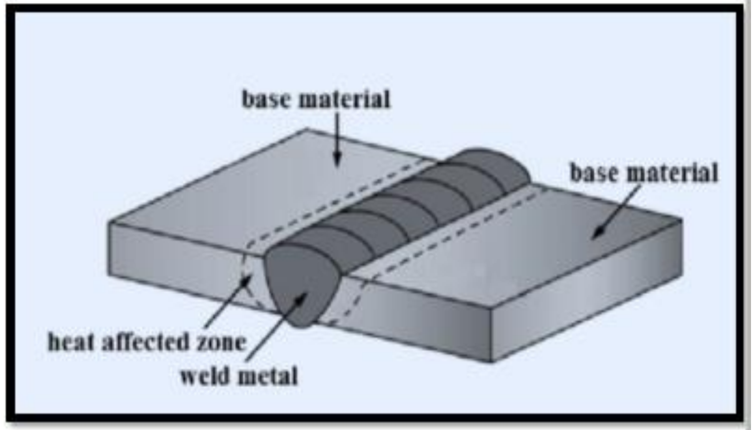
The weld is said to be **good weld** it is **free from**:

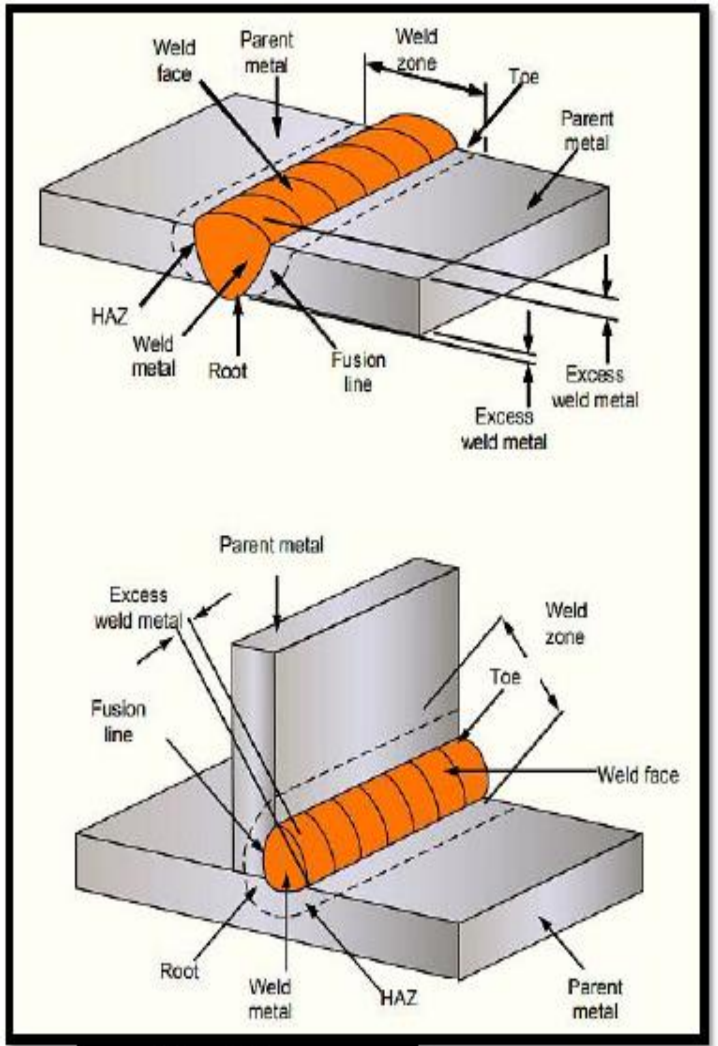
1. **External defects such as irregular width and heights of beads**,
2. Deviation of the weld from the prescribed dimensions,
3. **Unfilled craters on the surface of welds,**
4. Slag on the surface of welds,
5. **Porosity in the outer layer of the welds,**
6. Hidden porosity in the deposited metal,
7. **Hidden cracks in the weld and parent metal etc.**

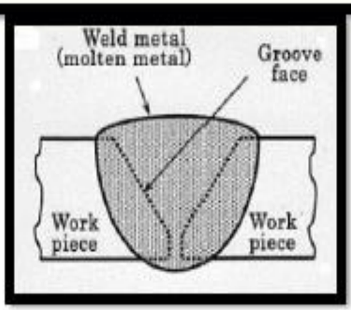


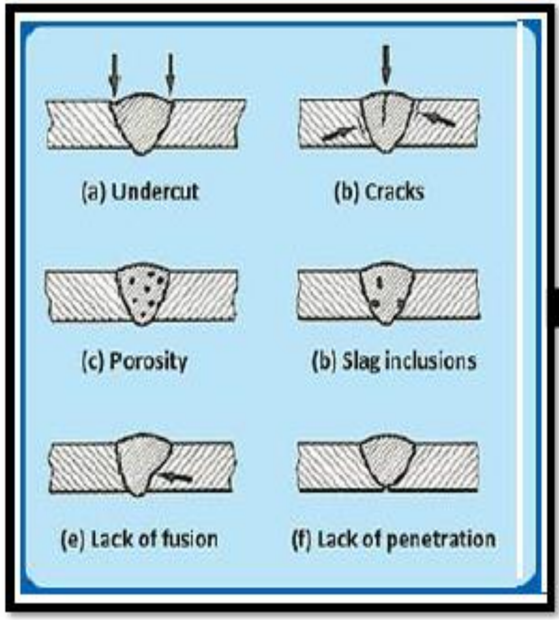












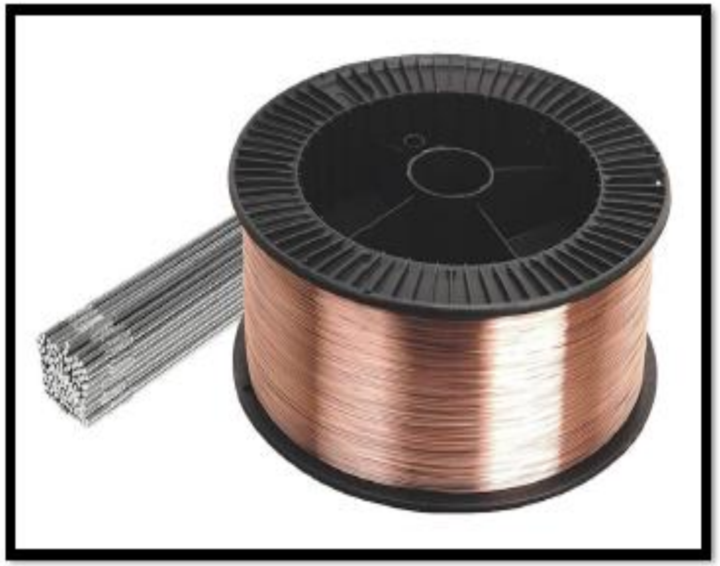
Welding Defects

Slag

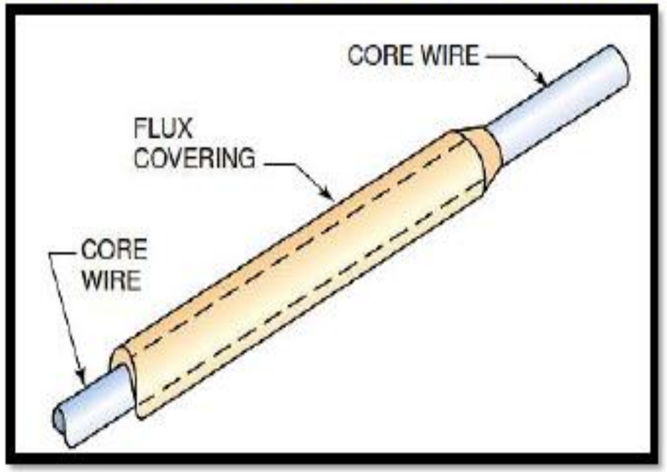
Welding Electrodes/Rods

- An **electrode** is a piece of wire or rod (of a metal or alloy), with or without flux covering, which carries current for welding. At one end it is gripped in a holder and an arc is set up at the other end.
- The functions of the **core wire include the following:**
  a. To carry the welding current.
  b. To serve as most of the filler metal in the finished weld
- The functions of the **flux covering include the following:**
  a. To provide some of the alloying elements.
  b. To provide an arc stabilizer (optional).
  c. To serve as an insulator.
  d. To provide a slag cover to protect the weld bead and slow cooling rate.
  e. To provide a protective gaseous shield during welding

BARE ELECTRODE



COATED / COVERED ELECTRODE



Types of Welding Electrodes

Non – Consumable Electrodes | **Consumable Electrodes**

Non – Consumable Electrodes	Consumable Electrodes
❑ A non-consumable electrode does not melt down or deposit on the weld bead. It remains intact throughout the welding.	❑ A consumable electrode itself melts down during welding and subsequently deposits on the weld bead.
❑ Non-consumable electrode does not supply filler. Thus filler material is required to supply separately.	❑ A consumable electrode acts as filler and thus it supplies necessary filler material intended to fill the root gap.
❑ After welding, the electrode remains unaffected (except a small erosion).	❑ After welding, a significant portion of the electrode becomes an integrated part of the weld bead.
❑ Since non-consumable electrode does not act as filler, so electrode material is independent of the parent materials to be welded.	❑ Electrode material must be chosen based on the parent materials in order to maintain chemical compatibility between them.
❑ A non-consumable electrode offers extended life as it is not consumed during welding. Frequent replacement is also not desired (it helps improving productivity).	❑ Since electrode material is consumed during welding, so frequent replacement of the electrode is usually desired. However, the replacement frequency depends on electrode size and filler deposition rate.
❑ Arc welding processes that employ a non-consumable electrode: a. Gas Tungsten Arc Welding (GTAW) or Tungsten Inert Gas (TIG) welding b. Atomic Hydrogen Welding (AHW) c. Carbon Arc Welding (CAW)	❑ Arc welding processes that employ a consumable electrode: a. Shielded Metal Arc Welding (SMAW) b. Gas Metal Arc Welding (GMAW) (both MIG and MAG) c. Flux-cored arc welding (FCAW) d. Submerged arc welding (SAW) e. Electro-slag welding (ESW) f. Electro-gas welding (EGW)

COMPARISON OF AC AND DC WELDING

DC Welding	AC Welding
❑ MG set or rectifier is required in case of availability in case of ac supply	❑ Only Transformer is required
❑ The cost of equipment is high	❑ The cost of equipment is cheap
❑ Arc stability is more	❑ Arc stable is weak or less
❑ Uniform heating	❑ Non – Uniform heating
❑ Both bare and coated electrodes can be used	❑ Only coated electrodes should be used.
❑ The operating power factor is high	❑ Operating power factor is low, thus, capacitors are required to improve the power factor.
❑ It is safer since no load voltage is low	❑ It is dangerous since no load voltage is high.
❑ The electric energy consumption is 5 – 10 kWh/kg of deposited metal.	❑ The electric energy consumption is 3 – 4 kWh/kg of deposited metal.
❑ Arc blow occurs due to the presence of non – uniform magnetic field.	❑ Arc blow not occurs due to uniform magnetic field.
❑ Efficiency is low.	❑ Efficiency is high.

COMPARISON BETWEEN RESISTANCE AND ARC WELDINGS

	Resistance welding	*Arc welding*
1	The source of supply is AC only.	The source of supply is either AC (1-ϕ or 3-ϕ) or DC.
2	The head developed is mainly due to the flow of contact resistance.	The heat developed is mainly due to the striking of arc between electrodes or an electrode and the workpiece.
3	The temperature attained by the workpiece is not so high.	The temperature of the arc is so high, so proper care should be taken during the welding.
4	External pressure is required.	No external pressure is required hence the welding equipment is more simple and easy to control.
5	Filler metal is not required to join two metal pieces.	Suitable filler electrodes are necessary to get proper welding strength.
6	It cannot be used for repair work; it is suitable for mass production.	It is not suitable for mass production. It is most suitable for repair works and where more metal is to be deposited.
7	The power consumption is low.	The power consumption is high.
8	The operating power factor is low.	The operating power factor is high.
9	Bar, roller, or flat type electrodes are used (not consumable).	Bare or coated electrodes are used (consumable or non-consumable).

- Arc welding requires a ***power source*** that can deliver electrical power at **low voltage and high current** such that it can **establish** and **sustain** an arc plasma column between the welding electrode and the work piece. **The welding power sources can have output of alternating current or direct current.**

Table Electric heating processes

Technique	*Frequency range*	*Power range*
Direct resistance	0–50 Hz	0.01–30 MW
Indirect resistance	50 Hz	0.5–5 kW
Oven, furnace	50 Hz	0.01–1 MW
Arc melting	50 Hz	1–100 MW
Induction heating	50 Hz–450 kHz	0.02–10 MW
Dielectric heating	1–100 MHz	1–5000 kW
Microwave heating	0.5–25 GHz	1–100 kW
Plasma torch	4 MHz	0.001–1 MW
Laser CO_2	30 THz	0.1–60 kW
Infra-red	30–400 THz	1–500 kW
Ultraviolet (mercury arc)	750–1500 THz	1 kW

Video Links

- https://www.youtube.com/watch?v=VpuNgEwExHE
- https://www.youtube.com/watch?v=zDsz_op-2ZE