3.1 Introduction

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

3.2 Advantages and disadvantages of electric heating

(a) Advantages

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

- <u>Economical:</u> Electric heating equipment is cheaper; they do not require much skilled persons; therefore, maintenance cost is less.
- <u>Cleanliness:</u> Since dust and ash are completely eliminated in the electric heating, it keeps surroundings clean.
- <u>Pollution free:</u> As there are no flue gases in the electric heating, atmosphere around is pollution free; no need of providing space for their exit.
- <u>Ease of control:</u> In this heating, temperature can be controlled and regulated accurately either manually or automatically.
- <u>Uniform heating:</u> The substance can be heated uniformly throughout whether it may be conducting or non-conducting material.
- <u>High efficiency:</u> 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.
- <u>Automatic protection:</u> Protection against over current and overheating can be provided by using control devices.
- <u>Heating of non-conducting materials:</u> The heat developed in the non-conducting materials such as wood and porcelain is possible only through the electric heating.
- <u>Better working conditions:</u> No irritating noise is produced with electric heating and also radiating losses are low.
- <u>Less floor area:</u> Due to the compactness of electric furnace, floor area required is less.
- <u>High temperature:</u> High temperature can be obtained by the electric heating except the ability of the material to withstand the heat.

(b) 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.

3.3 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:

(a) 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.
- It may be expressed in *[MJ/h/m²/m] or[W/cm²/cm]*
  t=Plat thickness in m
  A=X-sectional area of its two parallel face in m^2
  T_1 & T_2=Temperature of two face in °*C*
  T=duration of heat transfer in *hr*
  K=Co-efficient of thermal conductivity for the material in $MJ/m^2/m/°C/hr$

$$Q = \frac{kA}{t}(T_1 - T_2)T$$

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

(b) 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.
- Heat dissipated $H=a(T_1-T_2)^b$ in W/m^2
  a & b are constant (depends on heating surface)
  T_1 & T_2 are the temperature of the heating surface and fluid in °*C*
- Ex: Immersion water heater.

(c) 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.
  Heat dissipation

$$H = 5.72Ke\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right] watts/m^2$$

Where, T_1=Temperature of source of heat in °*C*
T_2= Temperature of substance to be heated in °*C*
K=Constant known as radiant efficiency
e=emissivity

- Ex: Solar heaters.

3.4 Essential requirements of good heating element

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

- High-specific resistance: Material should have high-specific resistance so that small length of wire may be required to provide given amount of heat.
- 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.
- Low temperature coefficient of resistance: 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.
- 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.
- High-mechanical strength: The material should have high-mechanical strength and should withstand for mechanical vibrations.
- Non-corrosive: The element should not corrode when exposed to atmosphere or any other chemical fumes.
- Economical: The cost of material should not be so high.

3.5 Classification of electric heating method

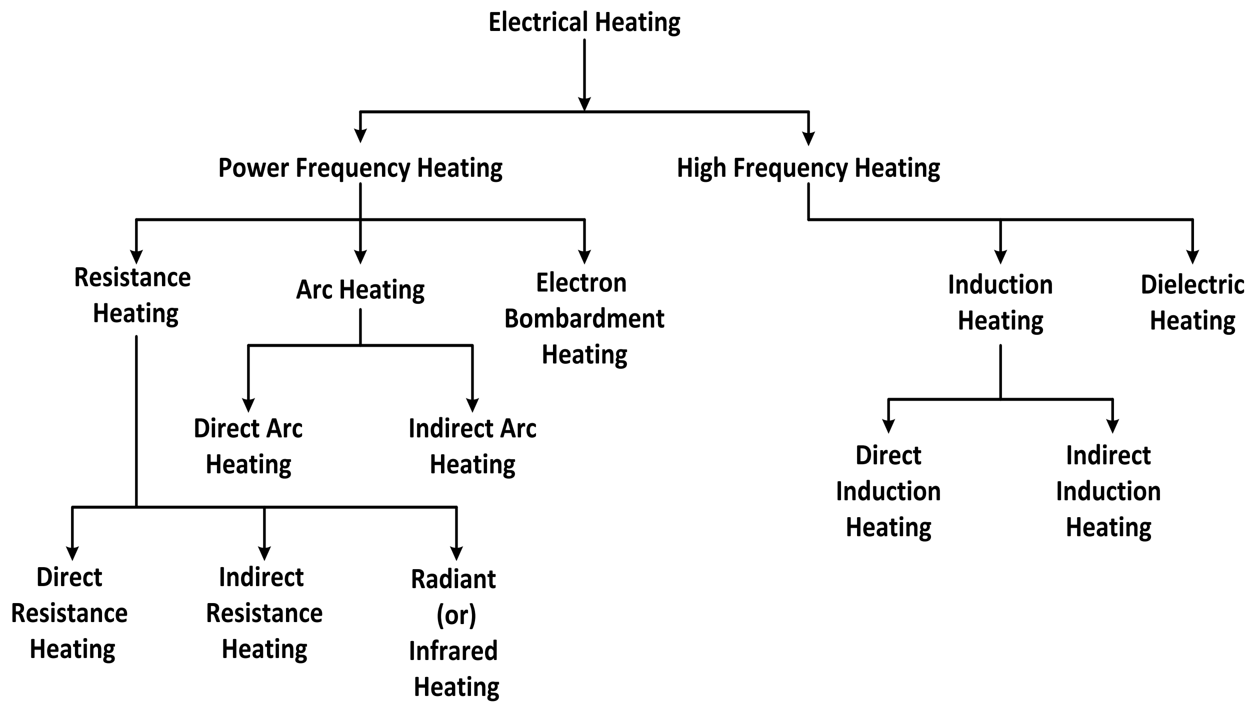

Figure 3.1 Classification of Electric Heating

Electric heating can be broadly classified under two categories:

(a) Power frequency heating in which the furnace operates with 50Hz AC supply.

(b) High frequency heating in which special high frequency generators is essential, e.g. dielectric heating, induction heating.

(A) <u>Power frequency heating</u>

1. Resistance heating

(i) Direct resistance heating

- The electric current is made to pass through the substance to be heated or charge itself. The electric current while passing through charge products I^2R loss which appears in the form of the heat thus charge is heated up.
- Few examples of this heating method are resistance welding, electrode boiler for heating water, salt bath furnace.

(ii) Indirect resistance heating

- Current is passed through heating element and I^2R loss is produced which appears in the form of heat.
- This heat is passed on to the substance or charge to be heated by radiation and convection.
- e.g. room heater, hair drier, soldering iron, immersion water heater, hot plate, frying pan, electric oven etc.

(iii) Radiant or Infrared heating

- Heat energy from an electric lamp is focused on the charge to be heated.
- The heat energy is transferred through electromagnetic radiations.
- This is used for drying the paint on objects.

2. Arc heating

(i) Direct arc heating

- An arc is made to strike between electrodes and charge itself.
- The heat energy of arc is absorbed by the charge and thus heating is done.

(ii) Indirect arc heating

- An arc is made to strike between two electrodes.
- The heat of arc is then passed on to the charge through radiation.

3. Electron bombardment heating

Bombardment of electron causes heating.

(B) <u>High frequency heating</u>

1. Induction heating

In this method, current are induced in the charge by electromagnetic induction action and circulation of these currents in the charge causes its heating. This is used in metallurgical industries for melting the metals.

(i) Direct induction heating

- Currents are induced in the charge by electromagnetic induction action in case of steel and other metals these currents are sufficient enough to melt the metals.
- The equipment used for melting is known as induction furnace and processes used for general heat treatment of metals is known as eddy current heating.

(ii) Indirect induction heating

- Eddy currents are induced in the heating element by electromagnetic induction, the heat so produced is transferred to the charge by radiation and convection and certain heat treatment methods for metals make use of this method.

2. Dielectric heating

Dielectric loss is produced in the charge itself when it is subjected to alternating electric field. This dielectric loss appears in the form of heat thus charge is heated up.

3.6 Resistance heating

- When current passes through a resistance, Power loss takes place there in which appears in the form of heat,
- Electrical energy converted into heat energy

$H = I^2Rt$

Power loss = I^2R *Watts*

= VI *Watts*

= V^2/R *Watts*

Where,

R=Resistance of the element (Ω)

V=Voltage (*Volt*)

I=Current (*ampere*)

(a) Direct Resistance Heating

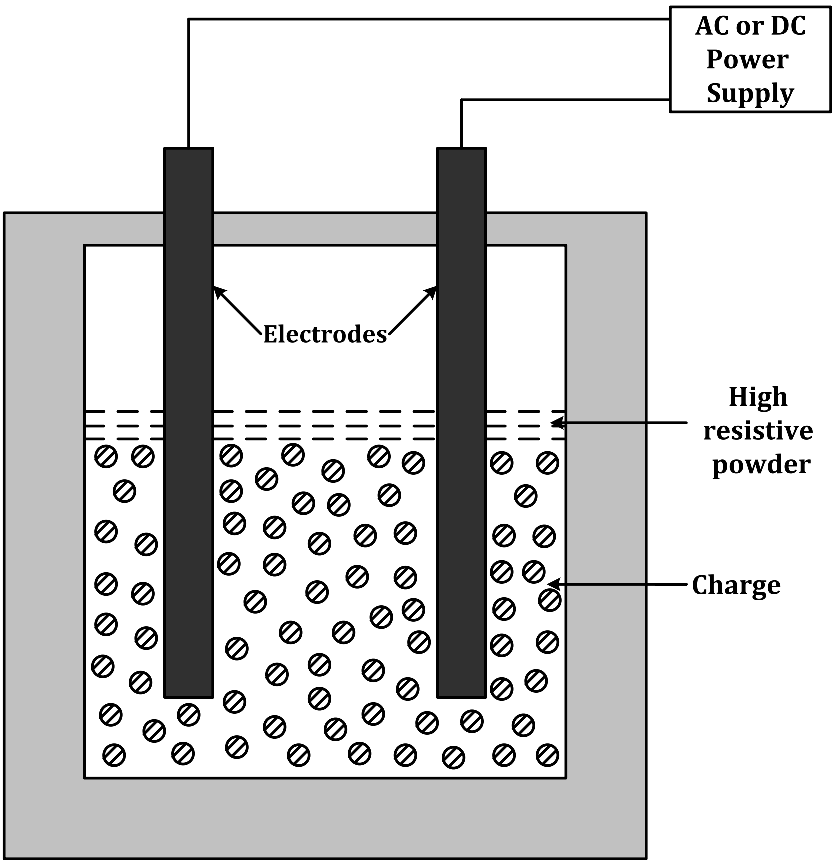

Figure 3.2 Direct Resistance Heating

- 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.
- In case of DC or 1-Φ AC, two electrodes are immersed and three electrodes are immersed in the charge and connected to supply in case of availability of 3- Φ supply.

- When metal pieces are to be heated, the powder of highly resistive is sprinkled over the surface of the charge (or) pieces to avoid direct short circuit between electrodes.
- 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.

(b) Indirect Resistance Heating

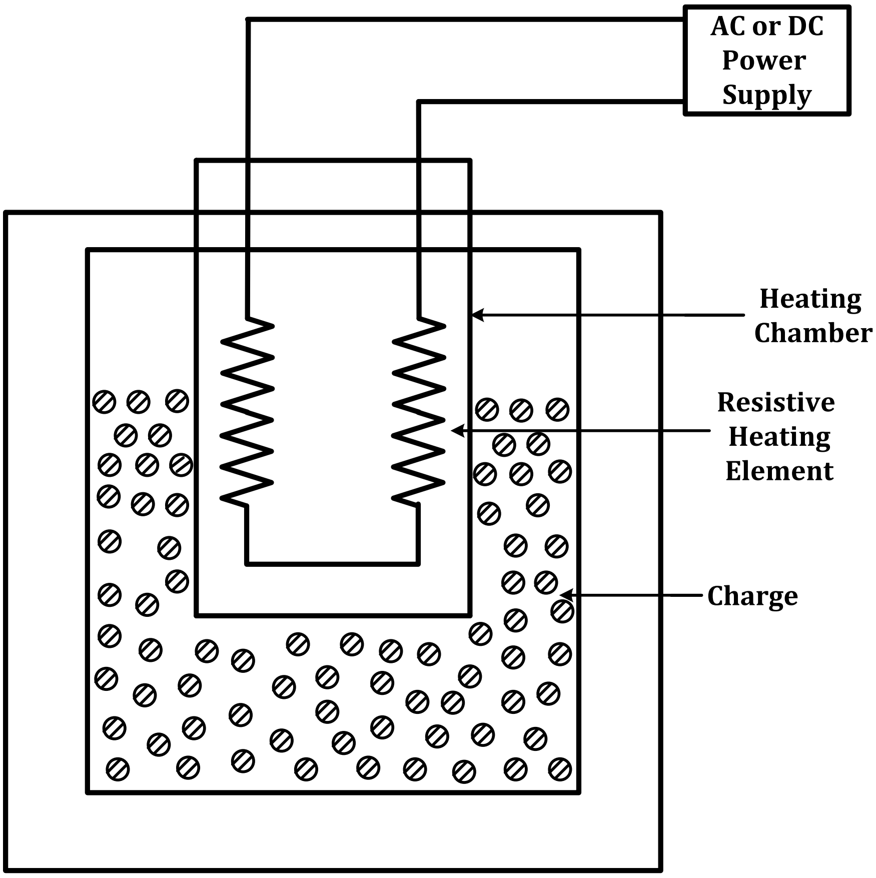

Figure 3.3 Indirect Resistance Heating

- In this method of heating, electric current is passed through a wire or other high resistance material forming a heating element.
- The heat proportional to I^2R loss produced in the heating element is delivered to the charge by one or more of the modes of transfer of heat i.e. convection and radiation.
- An enclosure known as heating chamber is required for heat transfer by radiation and convection for the charge.
- For industrial purposes, where a large amount of charge is to be heated then the heating element is kept in a cylinder surrounded by jacket containing the charge.
- The arrangement provides as uniform temperature, automatic temperature control can be provided.
- Both A.C and D.C supplies can be used for this purpose at full mains voltage depending upon the design of heating element.

3.7 Causes of failure of heating elements

(a) Formation of hot spot

- The filament may break where it shines brightest during its operation that means the temperature at the particular spot is higher compared to rest of the filament. This is called formation of the hot spots. It may be created due to following causes:
- Unequal spacing: If spacing between the heating element is non-uniform then the temperature will be maximum where spacing is minimum and thus hot spot may be formed.
- Supporting Structure: If supporting structure is a bad conductor of heat then it will not transfer any heat, hence temperature of the heating element will be higher near the supports resulting in formation of hot spots.

(b) Oxidation

- The outer surface of the heating element which is open to atmosphere gets oxidized due to higher temperatures.
- During switching operation the oxide layer gets flicked off and due to this the inner surface is now open to atmosphere.

(c) Embrittlement due to gain growth

- All heating alloys containing iron tend to form large brittle grains at high temperatures.
- When cold, the heating elements are very brittle and liable to rupture easily on slightest handling and jerks.

(d) Corrosion

- Chemical fumes produced during industrial operations corrode the surface of the heating element where the actual contact of fumes with the heating element occurs.
- Due to this failure of the heating element occurs.

(e) Mechanical Failure

- During alloying, apportion of the heating element may have a higher content of higher resistivity material so this portion will produce more amount of heat for the same current. Thus, the heating element may be damaged.

3.8 Temperature control of resistance furnaces/ovens.

- Temperature control is necessary in resistance oven/furnaces – temperature may have to be kept constant or varied according to requirements.
- Control may be manual or automatic.
- In this heating heat developed depends upon I^2Rt or V^2t/R. So there are three ways in which the temperature can be controlled.

(1) By varying the applied voltage to the elements or current flowing through the element

- Voltage across the oven can be controlled by changing the transformer tapping. This is economical and most suitable if the transformer is to be used for stepping down the voltage for the supply to ovens or furnaces, but such conditions do not arise usually.
- Auto-transformer or induction regulator can also be used for variable voltage supply.
- Alternative voltage across the oven or furnace can be controlled by varying the impedance connected in series with the circuit. But this method is not economical as

power is continuously wasted in the controlling resistance. Therefore limited to small furnaces.

(2) <u>By varying the resistance of elements</u>

- Temperature can also be controlled by switching the various combinations of group of resistance used in the ovens or furnaces in the following ways.

(a) Use of variable number of element

- In this method, the number of heating elements in working is changed; so total power input or heat developed is changed.
- This method does not provide uniform heating unless the number of heating elements in the circuit at any particular instant is distributed over the surface area, which requires complicated wiring.

(b) Change of connections

- In this method the elements are arranged to be connected either all in series or all in parallel or combination of both star or in delta by means of switching at different instant according to the requirements. This is the simplest and most commonly used method of control.

(3) <u>By varying the ratio of on and off times of supply</u>

- An on-off switch can also be employed for temperature control but its use is restricted to small ovens.
- The time duration for which the oven is connected to the supply and the time duration for which it remains cut-off from the supply will determine the temperature.
- Here an oven is supplied through a thermostat switch which makes and breaks the supply connections at particular temperature.
- The ratio of time duration during which supply remains on to total time duration of an on-off cycle is an indication of temperature.
- The higher the ratio, the larger will be the temperature of the oven. Advantages of this method is that it is more efficient then series impedance method.

3.9 Design of resistance heating element

- The purpose of design of heating element is to find size and length of wire required as the heating element to produce the given temperature can be calculated when, we know the electrical input and voltage.
- Wire employed may be circular or rectangular like a ribbon.
- The heating element on reaching a steady temperature will dissipate the heat from its surface equivalent to electrical input.
- Generally the heat will be dissipated from the heating elements at high temperatures, it is reasonable to assume that whole of the heat energy is dissipated by radiation.
- Heat dissipated according to stefan's Law

$$H = 5.72Ke\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right] \text{watts} / m^2 \text{ ---------(1)}$$

Where, T_1*=Temperature of source of heat in °C*
T_2*=Temperature of substance to be heated in °C*
K=Constant known as radiant efficiency
e=Emissivity

- Electrical Input

$$P = \frac{V^2}{R} \quad \text{--} \quad (2)$$

Where, *V=Supply Voltage*
R=Resistance of Heating Element

(a) <u>Circular wire:-</u>

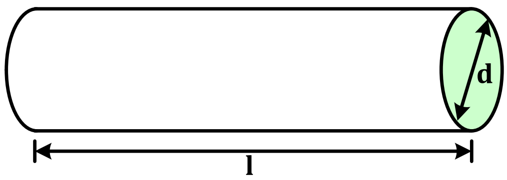

Figure 3.4 Circular Heating Elements

$$R = \frac{\rho l}{a} = \frac{\rho l}{\pi r^2} = \frac{\rho l}{\pi \left(\frac{d}{2}\right)^2} = \frac{\rho l}{\frac{\pi d^2}{4}}$$

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

Where, *d=Diameter of conductor*
l=Length of conductor
ρ=Resistivity of conductor material

- *Put in equ(2)*

$$P = \frac{V^2}{R} = \frac{V^2 \pi d^2}{4\rho l}$$

$$\boxed{\frac{l}{d^2} = \frac{\pi V^2}{4\rho P}} \quad \text{--} \quad (A)$$

- *Surface Area,* $S = \pi d l$
- *Total Heat Dissipated,* $H_t = \pi d l H$

Where, *H=Heat dissipated/Unit area*

- At Steady state temperature,

$$Power\ Input = Heat\ Dissipated$$

$$P = \pi d l H$$

$$\frac{\pi d^2 V^2}{4\rho l} = \pi d l H$$

$$\boxed{\frac{d}{l^2} = \frac{4\rho H}{V^2}} \quad \text{----------------------------------} \quad (B)$$

- Solving equation *(A)* and *(B)* length & diameter of wire can be determined.

(b) Rectangular (Ribbon) wire:-

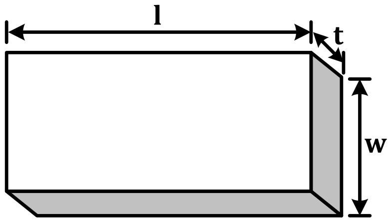

Figure 3.5 Rectangular Heating Elements

$$R = \frac{\rho l}{a} = \frac{\rho l}{wt}$$

Where, *w=width of conductor*
l=Length of conductor
t=thickness of conductor

- *Put in equ(2)*

$$P = \frac{V^2}{R} = \frac{V^2 wt}{\rho l}$$

$$\boxed{\frac{l}{wt} = \frac{V^2}{\rho P}} \text{ --- (C)}$$

- *Surface Area,* $S = 2wl + 2(tl + tw)$
- *Neglecting the side area 2(tl+tw) as the thickness is negligible*
- *Total Heat Dissipated,* $H_t = 2wlH$

Where, *H=Heat dissipated/Unit area*

- *At Steady state temperature,*

$$Power\ Input = Heat\ Dissipated$$

$$P = 2wlH$$

$$\frac{V^2 wt}{\rho l} = 2wlH$$

$$\boxed{\frac{t}{l^2} = \frac{2\rho H}{V^2}} \text{ ----------------------------------- (D)}$$

- Solving equation (C) and (D) length, width and thickness of wire can be determined.

3.10 Electric immersion heater

- It works on the principle of heating effect of an electric current.

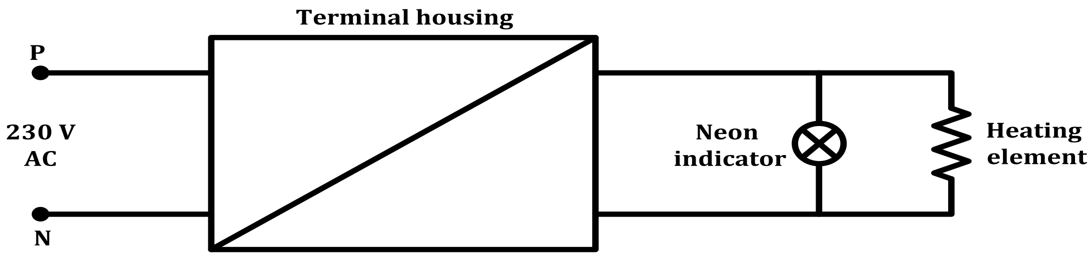

Figure 3.6 Electric Immersion Heater

- Metallic tube:- The tube is made of copper and chromium platted. It is a hollow tube and protects the inner part and absorbs the heat form the inner part and transmits the heat to the liquid or water to be heated.
- Heating element:- The heating element is made up of a high melting nicrome having more resistivity. It is in the form of a coil and placed inside the copper tube centrally. The coil is connected to the electric supply through the terminal housing and supply chord. The coil is heated up and produces the necessary heat.
- Insulating powder:- The gap between the heating element and the tube is filled with the insulating material like MgO. This material is having a good insulating property at high temperature and at the same time it is a good thermal conducting material.
- The other part such as terminal housing, supply chord, minimum water level indicator strip.
- It is used 0.5, 1, 3, 5 kW for heating water or liquids.
- If the two terminals are touching together it is a short circuit fault. This is checked by a test lamp.
- If there is a break in the heating element, this fault is a open circuit fault. It is checked by connecting a test lamp in series. If the lamp does not glow, it indicates the open circuit fault.
- One end of the test lamp is connected to one terminal of the heater and another is connected to the heater body. If the lamp glows there is an earth fault.

3.11 Electric water heater (Electric geyser)

- It is the special type of water heater working on the same principle of heating effect.

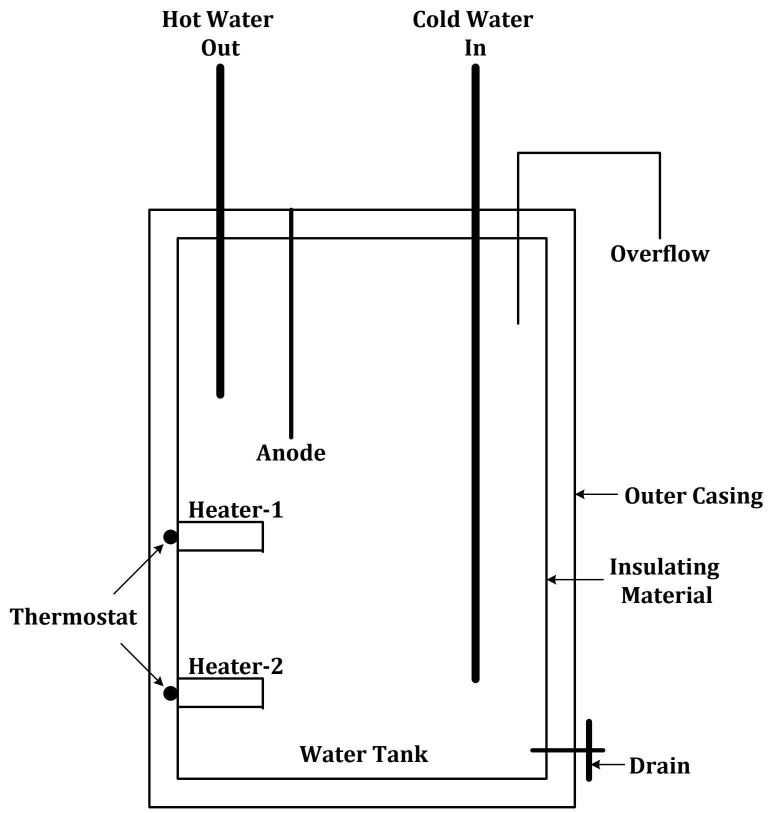

Figure 3.7 Electric Water Heater

- <u>Water storage tank:-</u> It has two cylinders one of which is called as heating chamber and is made of tinned copper. The outer part is made of lead coated steel. The remaining space between the two is filled up with the glass wool insulating material.
- <u>Heating element:-</u> The heating element made of nicrome wire may be one or two in numbers fitted in the chamber .
- Water inlet and outlet arrangement.
- <u>Anode:-</u> Anode rods come installed with geysers and are generally made of magnesium or aluminium which are screwed into the inside of the geyser. This anode prevents corrosion of the geyser by "self-sacrificing" its metal which attracts the corrosion of the water and its minerals preventing rust.
- <u>Thermostat:-</u> This is the automatic switching off arrangement after reaching the required temperature of the water.
- <u>Earthing arrangement:-</u> The body of the tank is well earthed to avoid the electric shock.
- Operation is similar to the immersion heater.

3.12 Arc heating

- The heating of matter by an electric arc. The matter may be solid, liquid, or gaseous. When the heating is direct, the material to be heated is one electrode; for indirect heating, the heat is transferred from the arc by convection, or radiation.
- Electrodes used in arc furnaces:

  <u>Carbon electrodes</u>
  - They are made of anthracite coal and coke.
  - Cheaper.
  - Uniform heating can be obtained with large area of carbon electrodes.
  - Oxidation starts at about 400°C.
  - Used in small furnaces.
  - Used in manufacturing of Ferro-alloys, aluminum, calcium carbide, phosphorus.

  <u>Graphite electrodes</u>
  - They are obtained by heating carbon electrodes to a very high temperature.
  - Owing to lower resistivity of graphite (one fourth of the carbon), graphite is required half in size for the same current resulting is easy replacement.
  - Oxidation starts at about 600°C.

  <u>Self - baking electrodes</u>
  - They are made of a special paste, the composition of the paste depends upon the type of process for which it is employed.
  - When current is passed, heat is produced that bakes the paste to form an electrode.
  - Used production of Ferro-alloys, electro- chemical furnaces and in production of aluminum by electrolytic process.

Types of arc heating furnaces

(a) Direct arc furnaces

- When supply is given to the electrodes, two arcs are established between electrodes and charge, current passes through the charge.

- 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.
- 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 and such furnace is used for manufacturing alloy steel and gives purer product.

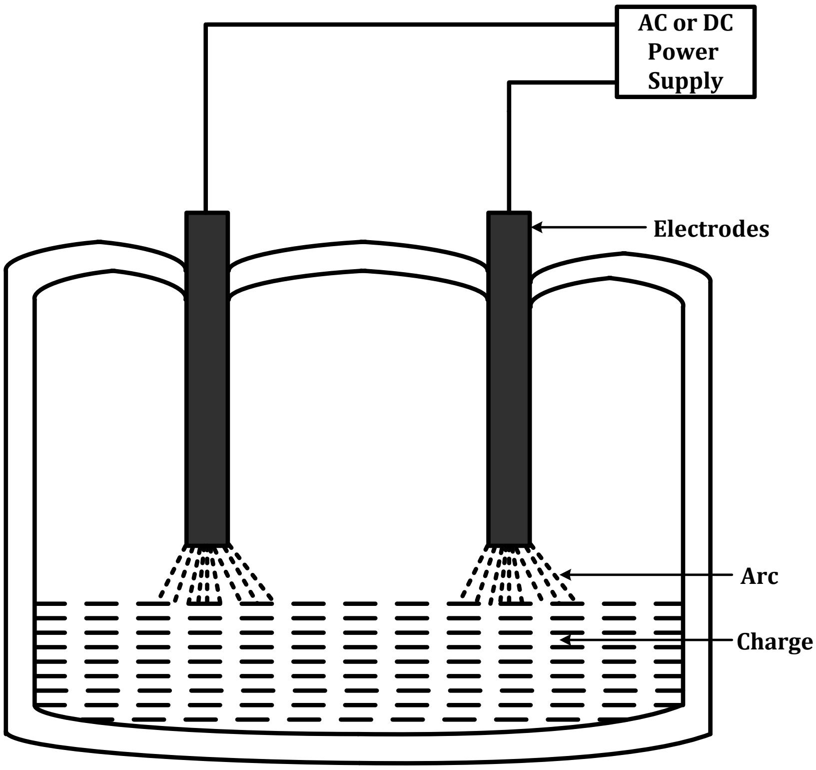

Figure 3.8 Direct Arc Furnace

- Merits:
    - It produces purer products, when compared with other methods.
    - It is very simple and easy to control the composition of the final product during refining process.
- Demerits:
    - It is very costlier.
    - Electric energy is expensive, Even though it is used for both smelting and refining.
- Application:
    - This type of furnace is to produce steel, alloy steel such as stainless steel etc.
    - Used for the manufacture of gray iron casting.

(b) 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.
- 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.

- Since on this furnace current does not flow through the charge, there is no stirring action and the furnace is required to be rocked mechanically.

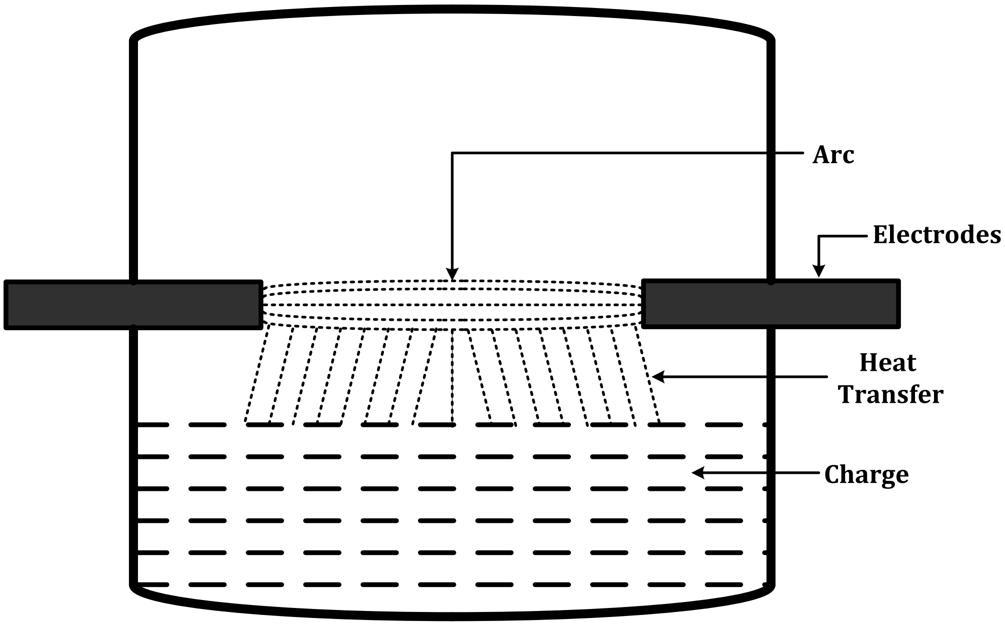

Figure 3.9 Indirect Arc Furnace

- 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.
- Power input to the furnace is regulated by adjusting the arc length by moving the electrodes.
- Even though it can be used in iron foundries where small quantities of iron are required frequently, the main application of this furnace is the melting of non-ferrous metals.
- Advantages:
  - Lower overall production cost per tonne of molten material.
  - Sound casting in thin and intricate design can be produced.
  - Metal losses due to oxidation and volatilization are quite low.
  - Flexible in operation.
- Disadvantages:
  - No inherent stirring action as there is no current flow through the charge.
  - Continuous rocking should be done to distribute heat uniformly.
- Application:
  The main application of this type furnace is melting of non-ferrous metals.

3.13 Induction heating

- Induction heating is based on the principle of transformers. There is a primary winding through which an AC current is passed.

- The coil is magnetically coupled with the metal to be heated which acts as secondary. An electric current is induced in this metal when the AC current is passed through the primary coil.
- The following are different types of induction furnaces:
  - Core type (low frequency) induction furnaces.
  - Coreless type (high frequency) induction furnaces.
- Core type furnaces: they operate similar to a two winding transformer. They are classified into three types. They are 1. Direct core type 2. Vertical core type 3. Indirect core type.

(a) Direct core type induction furnace

- The core type furnace is essentially a transformer in which the charge to be heated forms single turn secondary circuit and is magnetically coupled to the primary by an iron core.
- 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: (why it is used in low frequency?)
  - 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.

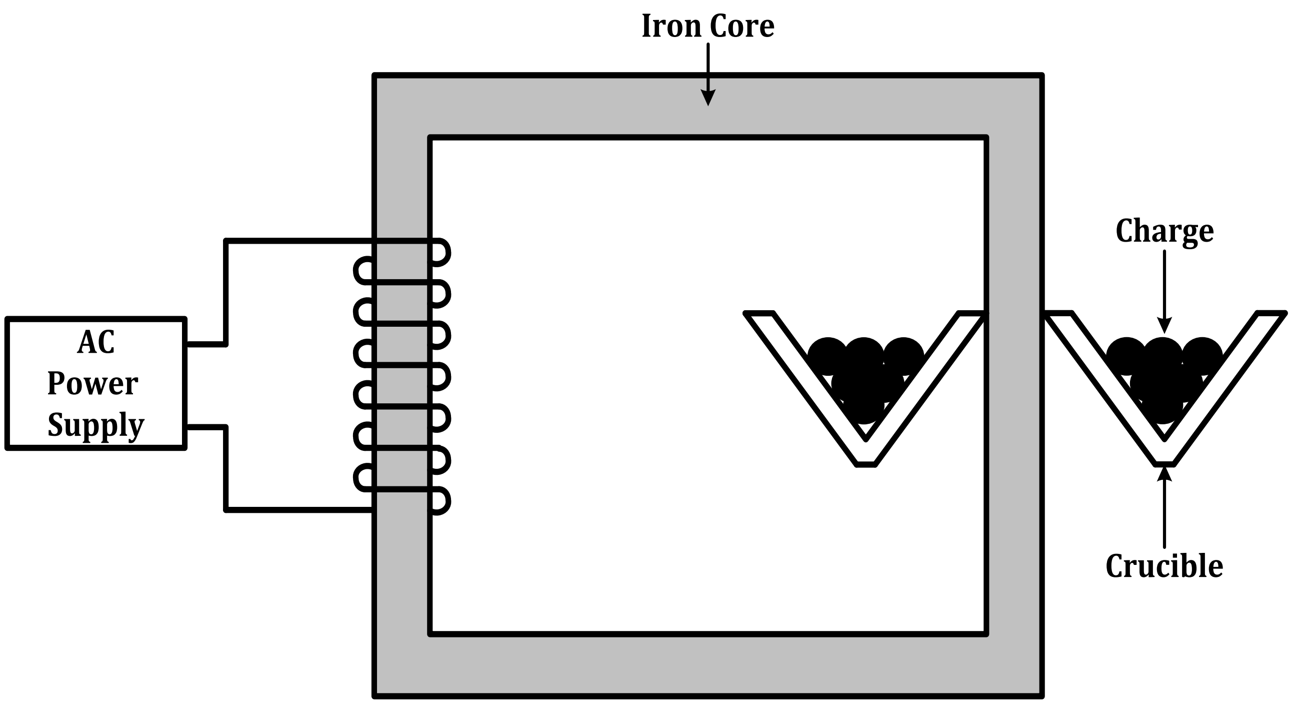

Figure 3.10 Direct Core Type Induction Furnace

  - 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.
- o The crucible used for the charge is of odd shape and inconvenient from the metallurgical viewpoint.
- o If current density exceeds about 500 A/cm^2, it will produce high-electromagnetic forces in the molten metal and hence adjacent molecules repel each other, as they are in the same direction.
- o The repulsion may cause the interruption of secondary circuit (formation of bubbles and voids); this effect is known as pinch effect.

- The pinch effect is also dependent on frequency; at low frequency, this effect is negligible, and so it is necessary to operate the furnace at low frequency.

(b) Vertical core type induction furnace

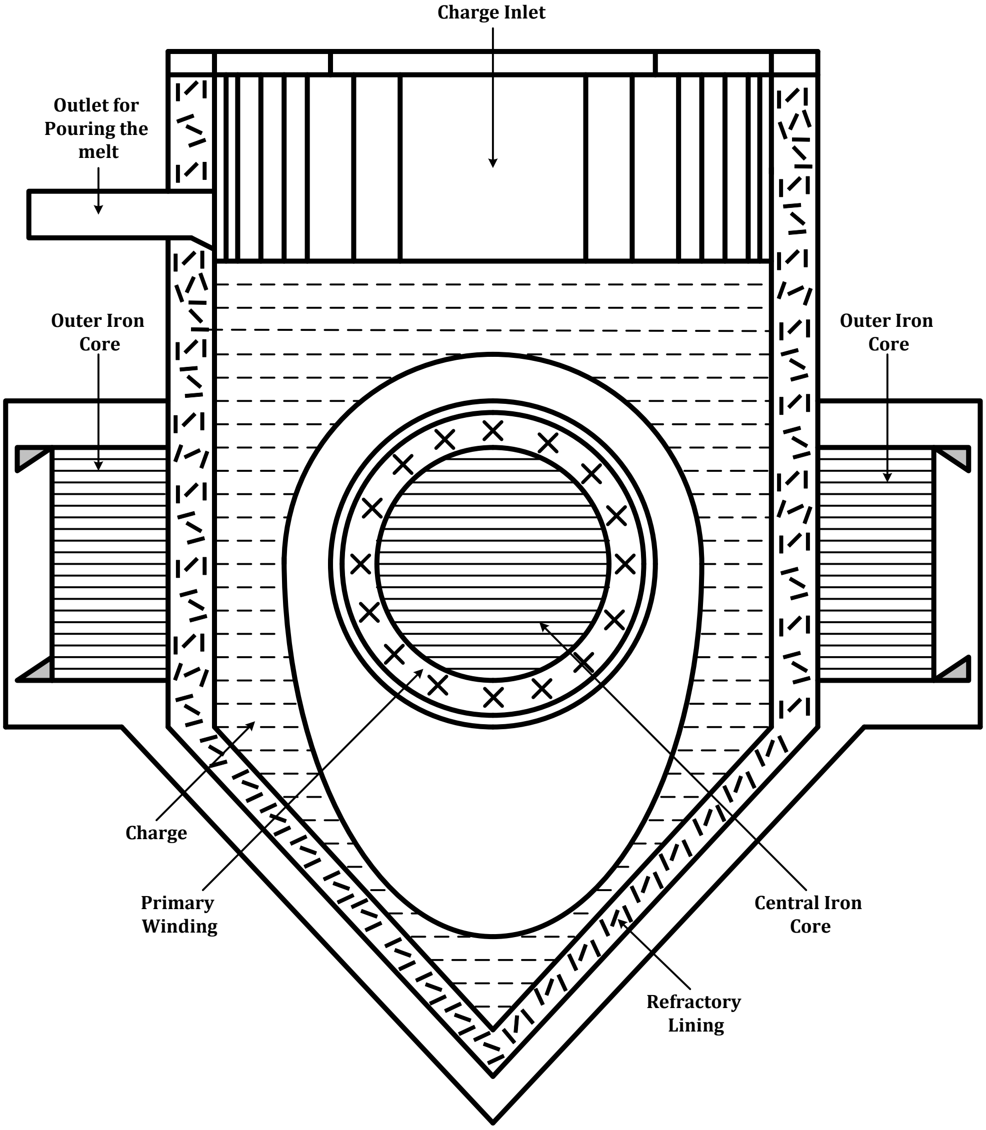

Figure 3.11 Ajax-Wyatt Induction Furnace (Vertical Core Type Induction Furnace)

- It is an improvement over the direct core type furnace, to overcome some of the disadvantages mentioned in direct core type induction furnace. This type of furnace consists of a vertical core instead of horizontal core. It is also known as 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.
- The top surface of the furnace is covered with insulating material, which can be removed for admitting the charge.
- Necessary hydraulic arrangements are usually made for tilting the furnace to take out the molten metal. Even though it is having complicated construction, it is operating at power factor of the order of 0.8-0.83.
- This furnace is normally used for the melting and refining of brass and nonferrous metals.
- Advantages
  - Accurate temperature control and reduced metal losses.
  - Absence of crucibles.
  - Consistent performance and simple control.
  - It is operating at high power factor.
  - Pinch effect can be avoided.

(c) 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.
- 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 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. Thus, the Temperature of the furnace can be effectively controlled.
- The magnetic circuit is detachable type that can be replaced by the other magnetic circuits having critical temperatures ranging between 400°C and 1,000°C. The furnace operates at a pf of around 0.8.

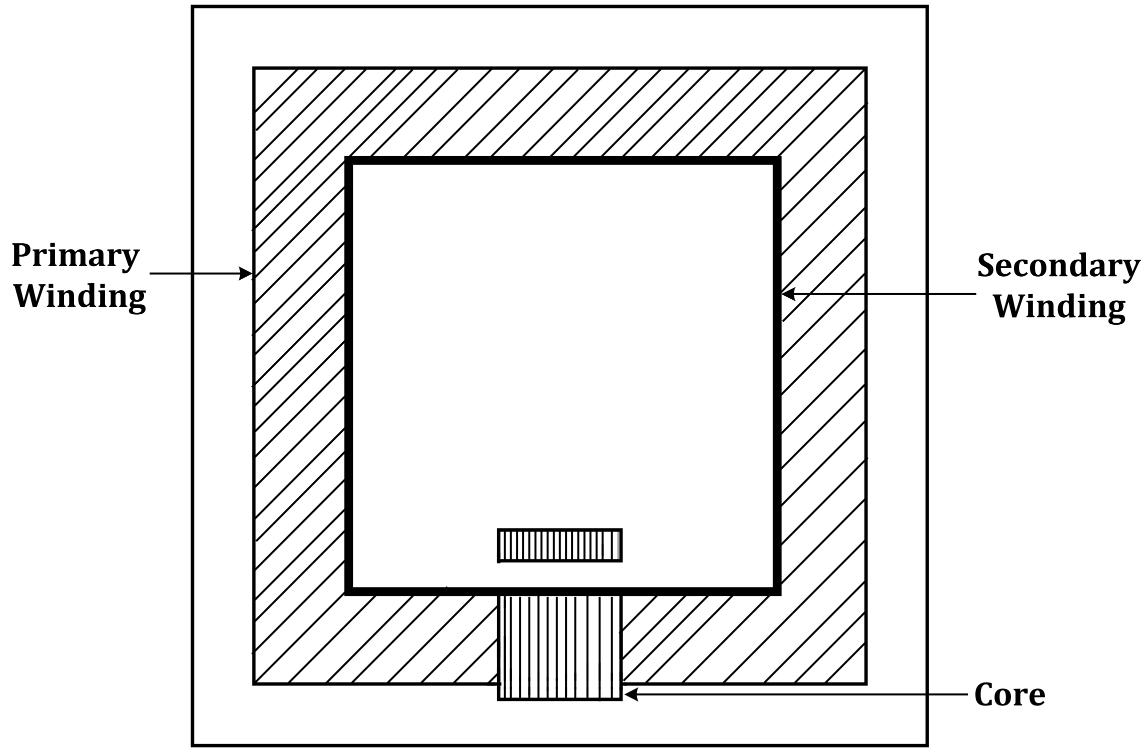

Figure 3.12 Indirect Core Type Induction Furnace

(d) Coreless type induction furnace

- It is a simple furnace with the absence of core. In this furnace, heat developed in the charge due to eddy currents flowing through it. 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 non-conducting container that acts as secondary. If the container is made up of conducting material, charge can be conducting or non-conducting; 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:
  $W_e \propto B_m^2 f^2$
  Where B_m is the maximum flux density (Tesla), f is the frequency in (Hz) and W_e is the eddy current loss (Watts).
- In coreless furnace, the flux density will be low as there is no core. Hence, the primary supply should have high frequency for compensating the low flux density.
- If it is operating at high frequency, due to the skin effect, it results copper loss, thereby increasing the temperature of the primary winding.

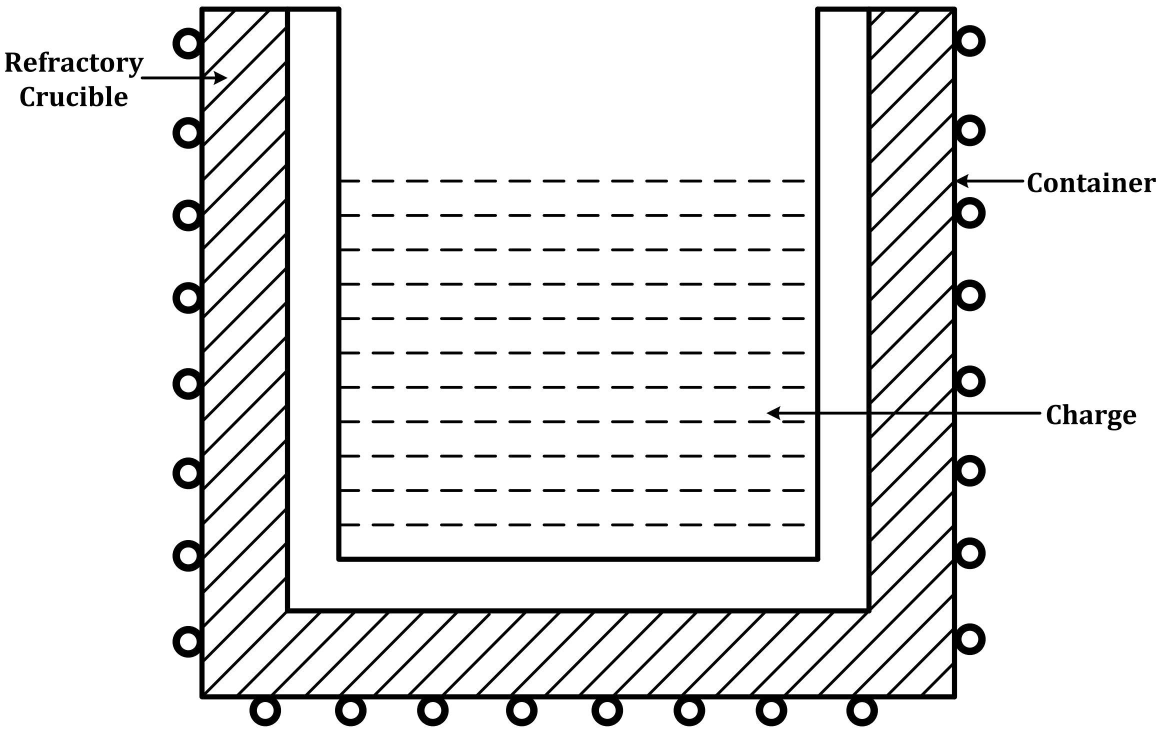

Figure 3.13 Coreless Induction Furnace

- This necessitates in artificial cooling. The coil, therefore, is made of hollow copper tube through which cold water is circulated.
- Minimum stray magnetic field is maintained when designing coreless furnace, otherwise there will be considerable eddy current loss.
- Following are the advantages of coreless furnace over the other furnaces:
  - Ease of control.
  - Oxidation is reduced, as the time taken to reach the melting temperature is less.
  - The eddy currents in the charge itself results in automatic stirring.
  - The cost is less for the erection and operation.
  - It can be used for heating and melting.
  - Any shape of crucible can be used.
  - It is suitable for intermittent operation.

3.14 Principle of dielectric heating

- Dielectric heating is also sometimes called as high frequency capacitance heating. if non metallic materials i.e., insulators such as wood, plastics, china clay, glass, ceramics etc are subjected to high voltage AC current, their temperature will increase in temperature is due to the conversion of dielectric loss into heat.
- The supply frequency required for dielectric heating is between 10-50 MHz and applied voltage is 20 kV.
- The overall efficiency of dielectric heating is about 50%.
- When a capacitor is subjected to a sinusoidal voltage, the current drawn by it is never leading the voltage by exactly 90°. The angle between the current and the voltage is

slightly less with the result that there is a small in-phase component of the current which produces power loss in the dielectric of the capacitor.

- At ordinary frequency of 50 Hz such loss may be small enough to be negligible but at high frequencies the loss becomes large enough to heat the dielectric. It is this loss that is utilized in heating the dielectric.
- The insulating material is placed in between two conducting plates in order to form a parallel plate capacitor shown in figure 3.14.
- The dielectric loss is dependent upon the frequency and high voltage. Therefore for obtaining high heating effect high voltage at high frequency is usually employed.
- The charge to be heated is placed between two sheet type electrodes which form a capacitor.
- Power drawn from supply, $P = VI\cos\Phi$

  Now, $I_c = I = V/X_c = 2\Pi fCV$

  $P = V(2\Pi fCV)\cos\Phi = 2\Pi fCV^2\cos\Phi$

  Now, $\Phi = (90°-\delta)$

  $\cos\Phi = \cos(90°-\delta)$

  $= \sin\delta = \tan\delta = \delta$. If δ is assumed to be very small.

  $P = 2\Pi fCV^2\delta$

  Here $C = \epsilon_o\epsilon_r A/t$

  Where, t - thickness of the dielectric slab

  A - area of the dielectric slab

  ϵ_r is the relative permittivity

  ϵ_o is the absolute permittivity of the vacuum (= 8.854×10^{-12} F/m).
- This power is converted into heat. Since for a given insulation material C and δ are constant, the dielectric loss α V^2f.

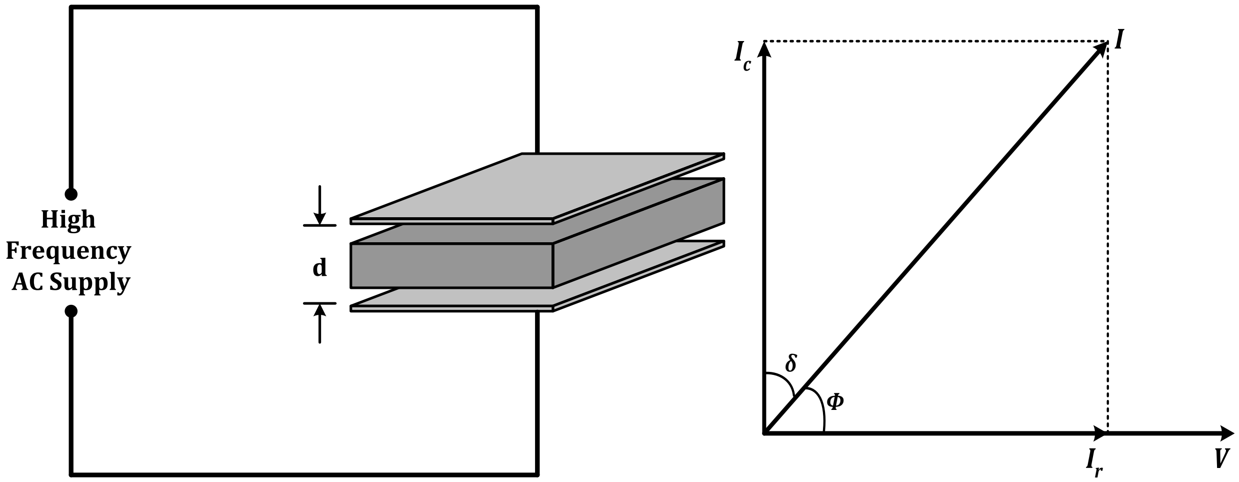

Figure 3.14 Dielectric Heating

- Advantages:
  - Uniform heating is obtained.
  - Running cost is low.
  - Non conducting materials are heated within a short period.
  - Easy heat control.

  - With increase in frequency the heating becomes faster.
  - Inflammable articles like plastics and wooden products can be safely heated.
- Disadvantages:
  - High installation cost. So preferred where other methods are not possible.
- Applications:
  - Food processing.
  - Wood processing.
  - Drying purpose in textile industry.
  - Electronic sewing.
  - Dehydration of foods.
  - Vulcanizing of rubber.
  - Drying of explosives.
  - Heating of tissues and bones of body required for the treatment of certain types of pains and diseases.
  - Removal of moisture from oil.

3.15 High frequency eddy current heating

- In high frequency eddy current heating, the phenomenon of 'skin effect' plays as important role.
- Skin effect is the tendency of induced heating currents to concentrate near the surface of the conductor.
- Skin effect is very predominant at high frequency.
- The charge to be heated is placed within a high frequency current carrying coil, an alternating magnetic field is set up and eddy currents are set up in the charge.
- The eddy current loss is proportional to the product of square of supply frequency and flux density therefore high frequency supply can be utilized to generate the heat.
- By controlling the frequency and the flux density the amount of heat can be controlled.
- The eddy current heating can be restricted to any desired depth of the material to heated by selection of frequency of heating current. The supply frequency is employed between 10,000 to 4,00,000 Hz.
- Advantages of eddy current heating:
  - It is quick, clean and convenient method.
  - The heat generated near the surface of material piece, therefore there is little wastage of heat.
  - Heat is produced at a very high rate; at time over 5 kW per sq cm of surface.
  - The area of the surface over which heat is produced can be accurately controlled.
  - Temperature control in very easy.
  - Unskilled labour can also operate the equipment.
- Disadvantages of eddy current heating:
  - The generation of heat is costly.
  - Efficiency of the equipment is less than 50%.
  - Initial cost of equipment is high.

- Applications of eddy current heating:
  - Surface heating.
  - Annealing of metal.
  - Soldering.
  - Welding.
  - Drying of point.
  - Forging of bolt heads.
  - Melting of costly metals.
  - Sterilization of surgical instruments.

3.16 Infra-red heating

- This is special type of heating.
- A tungsten filament special type of lamp is used.
- It is operated at the temperature of 2300°C.
- At this temperature the lamp emits a large amount of infra-red radiations.
- If we compare other types of resistance heating this lamp emits large amount of heat which is being reflected to the charge.
- These lamps with reflectors are mounted on the sides of walls or sometimes on the top.
- It does not permit the heat to leak through the surface of the chamber and hence heat insulation is not necessary.
- The reflectors are used and these are coated by Rhodium which increases heat emission intensities up to 7500 w/m^2.
- Heat absorbed by the charge is about 4300 w/m^2.
- Charge temperature is in between 200°C to 300°C.
- Applications of infra-red heating:
  - In paint drying industries for drying paints.
  - In the foundry sections of industry for molding.
  - De-hydration at low temperatures.
  - Heating of plastics at low temperatures.

3.17 Microwave heating

- A microwave oven is also known as microwave.
- It is a kitchen appliance that heats and cooks food by exposing it to electromagnetic radiation. These radiations are in the microwave spectrum.
- The process involves polar molecules in the food to rotate and produce thermal energy in a process known as dielectric heating.
- In other words intermolecular friction gives rise to heat and that heat is utilized for heating the substance itself.
- Microwave ovens heat food quickly and efficiently.
- A microwave oven heats food by passing microwave radiation through it.
- Microwaves are a form of non-ionizing electromagnetic radiation with a frequency higher than ordinary radio waves but lower than infrared light.
- This oven use frequencies in one of the ISM (industrial, scientific, medical) bands.
- The frequency used is about 2.45 GHz and a wavelength of 12.2 cm.

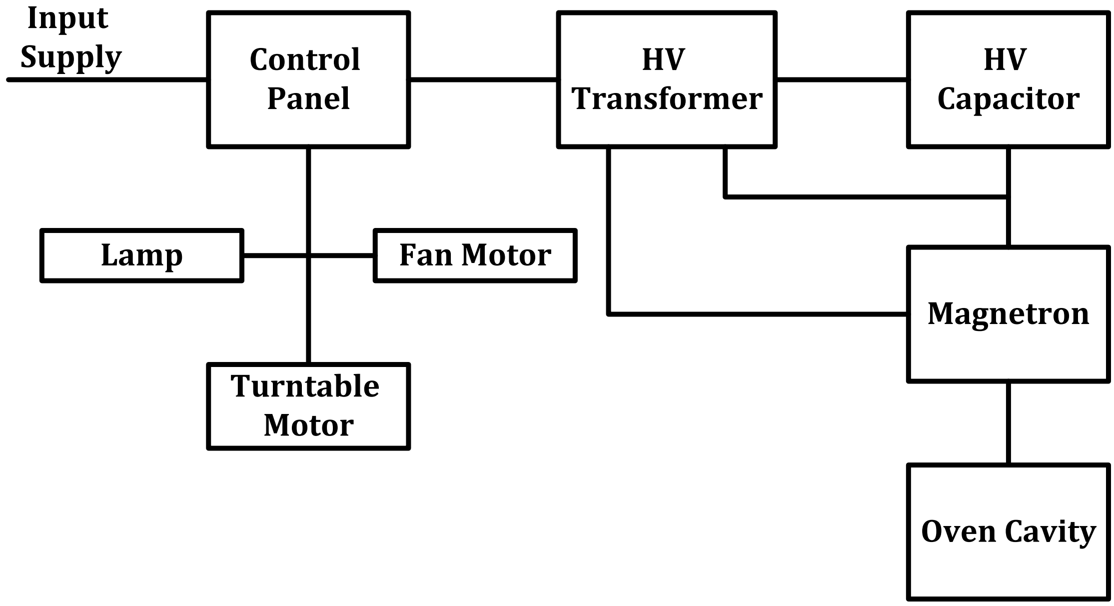

Figure 3.15 Microwave Oven Heating

- Water, fat and other substances in the food absorb energy from the microwaves in a process called dielectric heating. Many molecules are electric dipoles, meaning that they have a partial charge at one end and a partial negative charge at the other, and therefore rotate as they try to align themselves with the alternating electric field of microwaves.
- Rotating molecules hit other molecules and put them into motion, thus dispersing energy.
- Figure 7.14 shows simple diagram of microwave oven. It consists of vacuum tube cold magnetron, wave guide and container.
- The vacuum tube cold magnetron generates the necessary energy to pass microwave radiations to the substance to be heated. It consists of strong magnets and vacuum tube. The vacuum tube consists of tungsten and thorium.
- Wave guide it directs the microwave energy to the substance. The microwaves are thus focused on to the substance/food to get optimum heating. The intensity of these waves can be controlled by suitable method.
- Enclosure or container is used to keep the substance safely and to contain the microwaves within specific area. A rotating base is provided which helps to spread the microwaves uniformly over the substance to be heated.
- Application of Microwave heating:
  - Heating food items.
  - Microwave pasteurization and/or sterilization of foods.
  - Medical field Treating cancer. The treatment involves subjecting tumor tissue to localized heating, without damaging the healthy tissue around it.
  - Microwave heating is used in industrial processes for drying and curing products.