ELECTRICAL HEATING

Advantages. Methods of Electrialc heating – Resistance, arc, Induction and dielectric heating.

INTRODUCTION:

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

ADVANTAGES OF ELECTRIC HEATING:

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

(i) Economical: Electric heating equipment is cheaper; they do not require much skilled persons; therefore, maintenance cost is less.

(ii) Cleanliness: Since dust and ash are completely eliminated in the electric heating, it keeps surroundings cleanly.

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

(iv) Ease of control: In this heating, temperature can be controlled and regulated accurately either manually or automatically.

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

(vi) 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.

(vii) Automatic protection: Protection against over current and overheating can be provided by using fast control devices.

(viii) 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.

(ix) Better working conditions: No irritating noise is produced with electric heating and also radiating losses are low.

(x) Less floor area: Due to the compactness of electric furnace, floor area required is less.

(xi) High temperature: High temperature can be obtained by the electric heating except the ability of the material to withstand the heat.

(xii) Safety: The electric heating is quite safe.

Disadvantages of Electric Heating:

1. Expensive to operate. The cost of electricity makes it expensive to use as a heating fuel.
2. With space heaters, we can’t easily provide central filtration, humidification or cooling.

3. Some people would suggest that the electrical hazard of shock and fire caused by electricity is an issue.
4. There is a cost associated with Electric heat requires a larger electrical service than normal.

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 vicinityof an alternating magnetic field, heat is produced in the magnetic material (induction heating).Similarly it wasfound that when an electrically insulating material was subjected to electrical stresses; it too underwent a temperature rise (Dielectric heating).

MODES OF TRANSFER OF HEAT

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

1. conduction,
2. convection, or
3. radiation.

Conduction

In this mode, the heat transfers from one part of substance to another part without the movement in the molecules of substance. The rate of the conduction of heat along the substance depends upon the temperature gradient.

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

Convection

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

Ex: Immersion water heater.

Radiation

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

Ex: Solar heaters.

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.

CLASSIFICATION OF METHODS OF ELECTRIC HEATING:

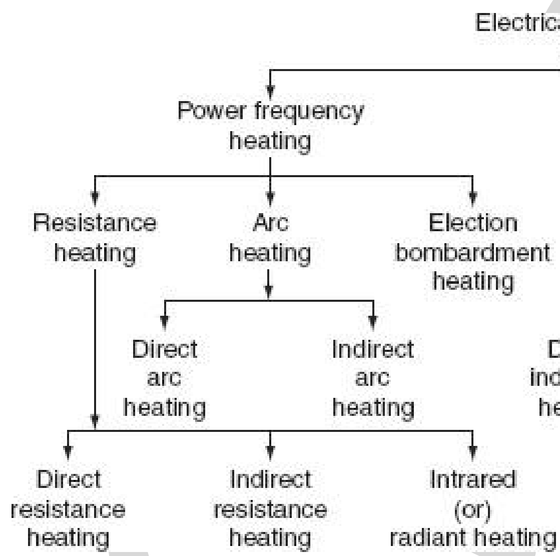


Fig. Classification of electrical heating

RESISTANCE HEATING:

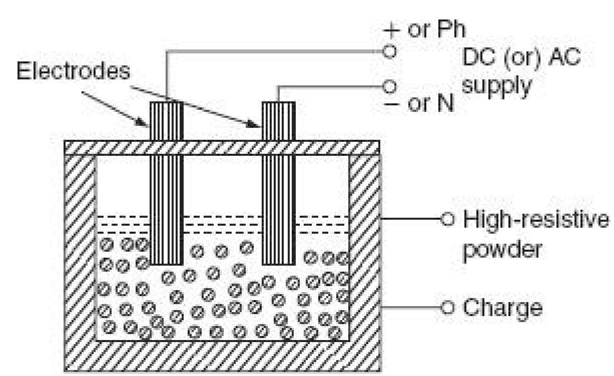
This method is based upon the I^2R loss. Whenever current is passed through a resistive material heat is produced because of I^2R loss.

There are two methods of resistance heating. They are:

(i) Direct Resistance heating and (ii) Indirect Resistance Heating

Direct Resistance heating

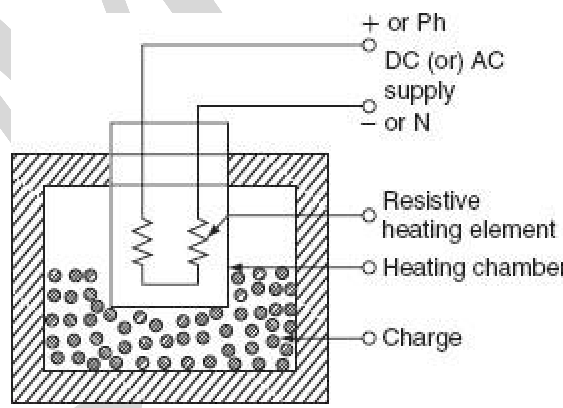
In this method, electrodes are immersed in a material or charge to be heated. The charge may be in the form of powder, pieces, or liquid. The electrodes are connected to AC or DC supply as shown in Fig. In case of DC or 1-Ø AC, two electrodes are immersed and three electrodes are immersed in the charge and connected to supply in case of availability of 3- Ø supply. When metal



pieces are to be heated, the powder of lightly resistive is sprinkled over the surface of the charge (or) pieces to avoid direct short circuit. The current flows through the charge and heat is produced in the charge itself. So, this method has high efficiency. As the current in this case is not variable, so that automatic temperature control is not possible. This method of heating is employed in salt bath furnace and electrode boiler for heating water.

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. conduction, convection and radiation. If the heat is transferred by conduction the resistor must be in contact with the charge. 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 fig. shows indirect resistance heating.



Advantages:

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.

Applications:

- This method is used in room heater.
- In bimetallic strip used in starters.
- Immersion water heaters.
- In various types of resistance ovens used in domestic and commercial cooking.

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:

1. Carbon electrodes:
    - They are made of anthracite coal and coke.
    - Cheaper.
    - Uniform heating can be obtained with large area of carbon electrodes.
    - Oxidation starts at about 600ºC.
    - Used in small furnaces.

- Used in manufacturing of Ferro-alloys, aluminum, calcium carbide, phosphorus.

2. Graphite electrodes:
   - They are obtained by heating carbon electrodes to a very high temperature.
   - Less amount of graphite about 1/4th of the carbon is required for same current rating.
   - Oxidation starts at about 600ºC.

3. Self - baking electrodes:
   - 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.

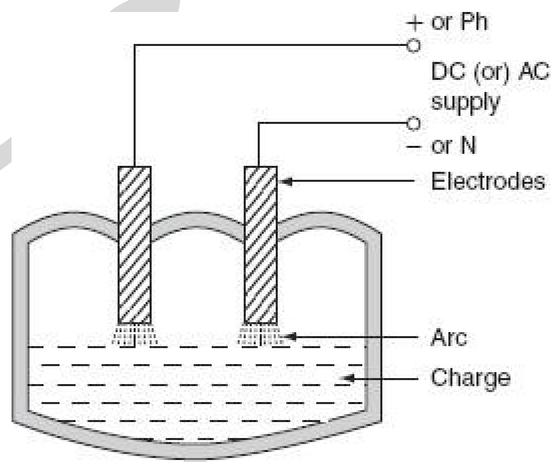
Types of arc heating furnaces:

(i) Direct arc furnaces (ii) Indirect arc furnaces (iii) submerged arc furnaces.

Direct arc furnaces:

When supply is given to the electrodes, two arcs are established and current passes through the charge, as shown in Fig. 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-Ø, AC, two electrodes are sufficient, if the supply is 3-Ø, AC, three electrodes are placed at three vertices of an equilateral triangle. The most important feature of the direct arc furnace is that the current flows through the charge, the stirring action is inherent due to the electromagnetic force setup by the current, such furnace is used for manufacturing alloy steel and gives purer product.



It operates at 0.8 lagging power factor

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:

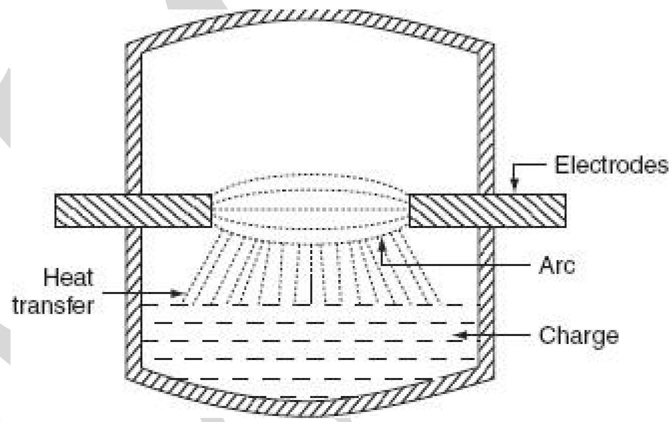
- It is very costlier.
- Electric energy is expensive, Even though it is used for both smelting and refining.

Application:

- This type of furnace is to produce steel, alloy steel such as stainless steel etc.
- Used for the manufacture of gray iron casting.

Indirect arc furnace:

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



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

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:

1. Lower overall production cost per tonne of molten material.
2. Sound casting in thin and intricate design can be produced.
3. Metal losses due to oxidation and volatilization are quite low.
4. Flexible in operation.

Disadvantages:

1. No inherent stirring action as there is no current flow through the charge.
2. Continuous rocking should be done to distribute heat uniformly.

Application:

The main application of this type furnace is melting of non-ferrous metals.

HIGH-FREQUENCY HEATING:

The main difference between the power-frequency and the high-frequency heating is that in the conventional methods, the heat is transferred either by conduction convection or by radiation, but in the high-frequency heating methods, the electromagnetic energy converted into the heat energy inside the material.

The high-frequency heating can be applied to two types of materials. The heating of the conducting materials, such as ferro-magnetic and non-ferro-magnetic, is known as induction heating. The process of heating of the insulating materials is known as dielectric heating. The heat transfer by the conventional method is very low of the order of 0.5-20 W/sq. cm. And, the heat transfer rate by the high-frequency heating either by induction or by dielectric heating is as much as 10,000 W/sq. cm. Thus, the high-frequency heating is most importance for tremendous speed of production.

INDUCTION HEATING:

Induction heating is based on the principle of transformers. There is a primary winding through which an a.c 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 a.c current is passed through the primary coil. The following are different types of induction furnaces:

1. Core type (low frequency) induction furnaces.
2. Coreless type (high frequency) induction furnaces.

Core type furnaces: they operate similar to a two winding transformer.

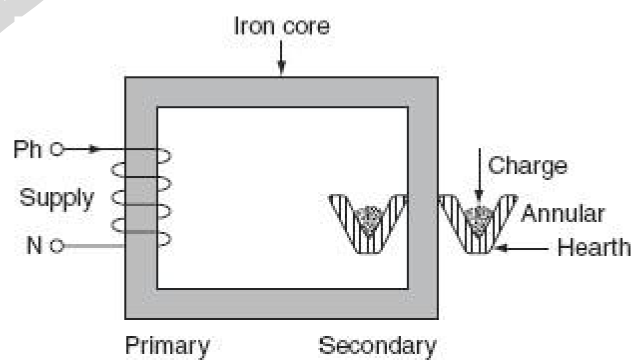
They are classified into three types. They are

A. Direct core type B. vertical core type. C. Indirect core type

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 as shown in Fig.

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:



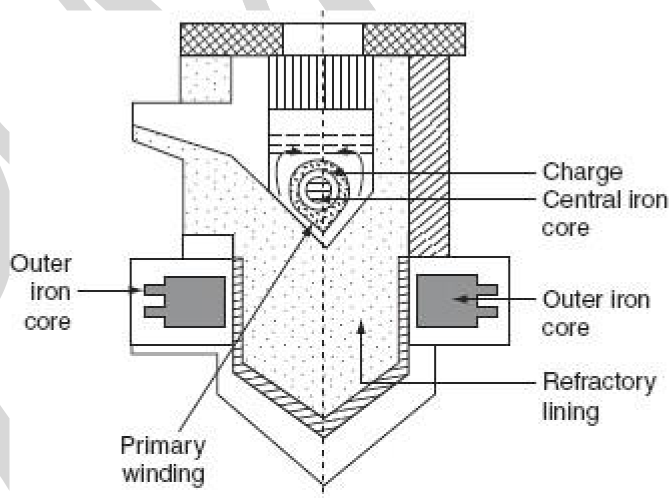
- This metal ring is quite large in diameter and is magnetically interlinked with primary winding, which is energized from an AC source. The magnetic coupling between primary and secondary is very weak; it results in high leakage reactance and low pf. To overcome the increase in leakage reactance, the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

- In order to obtain low-frequency supply, separate motor-generator set (or) frequency changer is to be provided, which involves the extra cost.
- The crucible used for the charge is of odd shape and inconvenient from the metallurgical viewpoint.
- 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. 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.

Vertical core type induction furnace :

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



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 non-ferrous metals.

Advantages

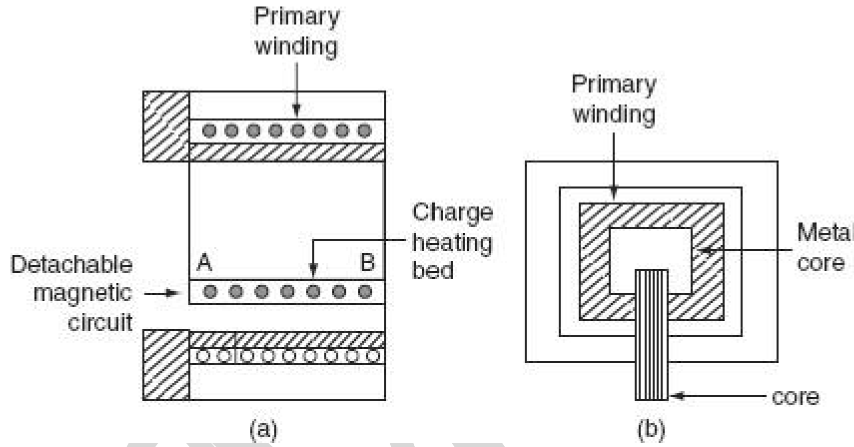
- Accurate temperature control and reduced metal losses.
- Absence of crucibles.
- Consistent performance and simple control.
- It is operating at high power factor.
- Pinch effect can be avoided.

Indirect core type furnace:

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

The secondary winding itself forms the walls of the container or furnace and an iron core links both primary and secondary windings.

The heat produced in the secondary winding is transmitted to the charge by radiation. An oven of this type is in direct competition with ordinary resistance oven.



It consists of a magnetic circuit AB is made up of a special alloy and is kept inside the chamber of the furnace. This magnetic circuit loses its magnetic properties at certain temperature and regains them again when it is cooled to the same temperature.

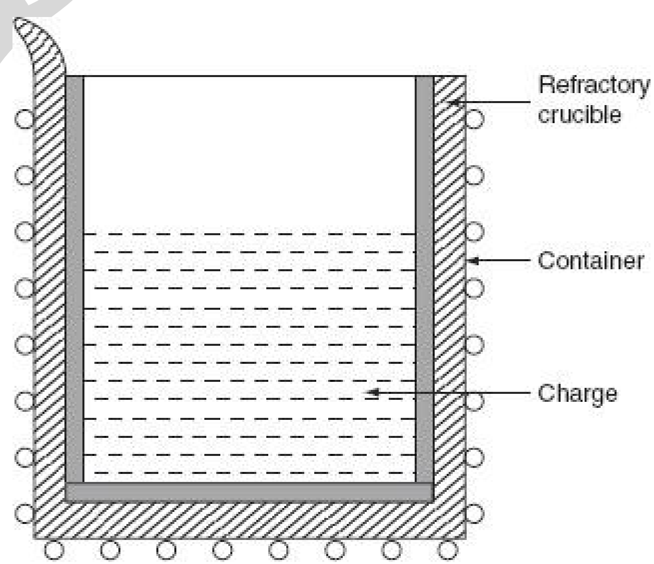
When the oven reaches to critical temperature, the reluctance of the magnetic circuit increases many times and the inductive effect decreases thereby cutting off the supply heat. Thus, the emperature of the furnace can be effectively controlled. The magnetic circuit ‘AB’ is detachable type that can be 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.

The main advantage of such furnace is wide variation of temperature control is possible.

Coreless type induction furnace:

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

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. 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.

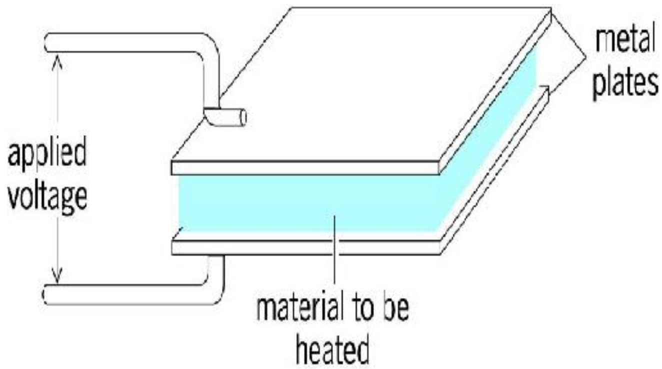
Dielectric heating is also sometimes called as high frequency capacitance heating. if non metallic materials i.e., insulators such as wood, plastics, china clay, glass, ceramics etc are subjected to high voltage A.C current, their temperature will increase in temperature is due to the conversion of dielectric loss into heat.

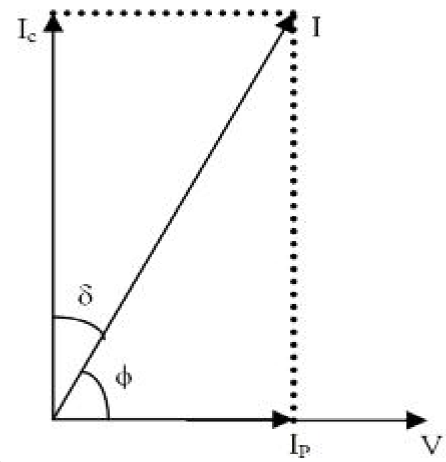
- The supply frequency required for dielectric heating is between 10-50 MHz and applied voltage is 20 KV.
- The overall efficiency of dielectric heating is about 50%.

Principle of Dielectric heating: 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 beating the dielectric. The insulating material is placed in between two conducting plates in order to form a parallel plate capacitor as shown in the fig.

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 metal to be heated is placed between two sheet type electrodes which form a capacitor as shown in fig. The equivalent circuit and vector diagram is also shown in fig.





Power drawn from supply = VI cos ϕ

Now, $I_c = I = \frac{V}{X_C} = \frac{V}{1/2\pi f C} = 2\pi fCV.$

$P = V\,(2\pi fCV)\cos\phi = 2\pi fCV^2\cos\phi$

Now $\phi = (90^o - \delta)$,

$\text{Cos}\,\phi = \cos(90^o - \delta)$

$= \sin\delta = \tan\delta = \delta.$ If δ is assumed to be very small, expressed in radians.

$P = 2\pi fCV^2\delta.$

Here $C = \frac{\varepsilon_o \varepsilon_r A}{t}.$

t - thickness of the dielectric slab and A - area of the dielectric slab, ε_r is the relative permittivity and ε_o- is the absolute permittivity of the vacuum (= 8.854 x 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.

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.

Example: A Slab of insulating material 130 cm^2 in area and 1 cm thick is to be heated by dielectric heating .The power required is 380W at 30MHz.Material has a relative permittivity of 5 and p.f. of 0.05.Absolute permittivity=$8.854 X 10^{-12}$ F/m.Determine the necessary voltage.

Solution:

Given A=130 cm^2 = 130 X 10^{-4}

t= 1 cm = 0.01 m, P=380 W

f=30 MHz ε_r=5 , ε_o= $8.854 X 10^{-12}$ F/m

$$Capacitance\ C = \frac{\varepsilon_0 \varepsilon_r A}{t}$$

$$= \frac{8.854 X 10^{-12}\ X\ 5\ X\ 130\ X\ 10^{-4}}{0.01} = 57.55\ X\ 10^{-12}\ F$$

$$P = 2\pi f C V^2 \cos\phi$$

$$380 = 2\pi\ X\ 30\ X\ 10^6\ X\ 57.55\ X\ 10^{-12}\ V^2 X 0.05$$

$$V^2 = \frac{380}{2\pi\ X\ 30\ X\ 10^6\ X\ 57.55\ X\ 10^{-12} X 0.05} = 700595$$

V=837 V.