unit-5 Heat Effects

- Electric Heating is the process of converting electrical energy into heat energy.
- Applications of electrical heating is heating of buildings, cooking, water heating and industrial processes etc.
- The heating element inside every electric heater is simply an electric resistor which works on the principle of Joule Heating.

⇒ Applications of Electric Heating - (Domestic)

- Room heater for heating the building
- Immersion water heater
- Hot plates for cooking
- Geysers
- Electric kettles
- Electric Iron
- Electric oven
- Electric Toasters etc.

Industrial Applications -

- melting of metals
- Electric welding
- moulding of glass for making glass appliances
- Baking of insulator
- moulding of plastic components
- Heat treatment of pointed surfaces

modes of Heat Transfer -

- 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 3) Radiation

1) Conduction - This phenomenon takes place in solids, liquids and gases. The rate of the conduction of heat along the substance depends upon the temperature gradient i.e

heat transfer is proportional to the difference of temperature b/n two surfaces/ faces/ points.

$\Rightarrow$ The amount of heat 'Q' passed through a cubic body with two parallel faces with thickness 't' meters, having cross sectional area 'A'. m^2, the temprature of its two faces is $T_1^{\circ}C$, $T_2^{\circ}C$, during 'T' hours is

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

'K' - coefficient of thermal conductivity for the material. $MJ/m^2/^{\circ}C/hr$.

Here no actual motion of molucels occurs.

2) Convection - the heat transfer takes place from one point to another due to actual motion of molecules.

- This takes place in liquids and gases.
- This is due to the difference in fluid density at different temperatures.

Ex $\Rightarrow$ Immersion Heaters.

$$\boxed{H = 3.875(T_1 - T_2)^{1.25} \quad W/m^2}$$

$H \rightarrow$ heat dissipated

T_1, T_2 - temperatures of heating element and fluid respectively

3) Radiation - In this method, the heat transfer is confined to surfaces.

$\rightarrow$ Radiant energy is emitted or absorbed is dependent on the nature of surface.

- The rate of heat dissipated is given by.

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

$K \rightarrow$ radiant efficiency or constant

$e \rightarrow$ emissivity

$T_1 \Rightarrow$ Temperature of source

$T_2 \Rightarrow$ temperature of substance to be heated.

Requirements of good heating material - are :-

1) High Specific - resistance
2) High melting point
3) Low temerature coefficient of resistance
4) free from oxidation
5) High - mechanical Strength
6) non - corrosive
7) High ductility and flexibility
8) Economical.

Examples of heating elements

1) Nichrome — Nickel + chromium alloy
80% Ni 20% Cr

2) Ni + Cr + Fe ⇒ 60% Ni + 16% Cr + 24% Fe

3) Nickel + copper → 45% Ni + 55% Cu → Eureka or Constantan

4) Iron + chromium + Aluminium
(Fe + Cr + Al) - 70% Fe + 25% Cr + 5% Al
— Kanthal

Resistance Heating -

This method is based on I^2R loss. when electric current passes through a resistive material, power loss takes place which appears in the form of heat.

$$\text{power Loss} = I^2R = \frac{V^2}{R} = VI$$

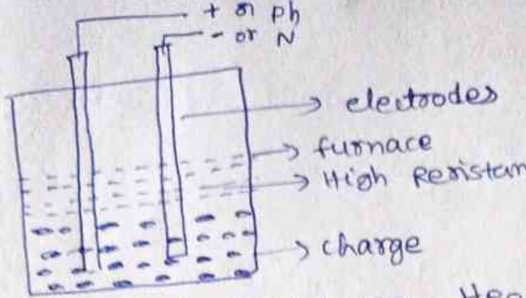
where I → current
V → voltage
R → resistance of the element.

there are 3 types of Resistance heating methods, they are

1) Direct Resistance heating
2) Indirect Resistance heating
3) Infrared or radiant heating.

① Direct Resistance Heating - In this method of heating electric current is passed through the body (charge) to be heated.
- The charge may be in the form of powder, pieces or liquid.

- The charge is placed in a furnace and two electrodes are immersed in the charge.
- These electrodes are connected to DC or AC supply as shown in the fig



Direct Resistance Heating.

- The resistance offered by the charge to the flow of current causes power loss in the form of I^2R. and it results in the heating of the charge.
- When metal pieces are to be heated, the powder of lightly resistive is sprinkled over the surface of 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.

- In this method heat transfer occurs due to conduction.

Advantages -
- this method is quite efficient
- uniform and high temperature can be obtained.

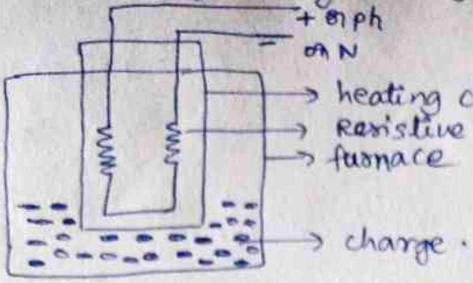
Disadvantages
- As the current is not easily variable, automatic temperature control is not possible.

Applications -
- scrap heating
- Resistance welding
- Salt bath furnace - steel production
- electrode boiler for water Heating.

2) Indirect Resistance Heating - The current is passed through a high resistive element (heating element) which is placed above or below the oven depending on the nature of the job

to be performed.

- It's as shown in the following diagram.



- Generally, charge will enclose the heating element for efficient heat transfer.
- The heat produced in the element is transferred to the charge by convection and/or Radiation methods.
- for industrial purposes, where a large amount of charge is to be heated then the heating element is kept in a cylinder surronded by jacket containing the charge.

Advantages -

- This method provides uniform and automatic tempe-rature control.
- Both AC and DC supplies can be used for this heating

Applications -

- Room heaters
- Immersion water heaters
- Industrial salt bath furnaces
- Starters (bimetallic strip)
- ovens used in domestic cooking.

Infrared or Radiation Heating -

In ordinary resistance furnances, the heat is transferred from heating elements to the charge partly by radiation & partly by convection, the later predominating at low and medium temperatures.

- when the temperature is high, the rate of heat transfer is more.
- for maximum operating temperature Nichrome, Tungsten etc will be used.

- Infrared or radiant heating is a form of heat energy transfer from Infrared radiant energy source.
- The same phenomenon is done in Infrared lamps, sun light, an electric wire or a flame heat source etc.
- Radiant heating is mainly used for drying enamel or painted surfaces.
- High concentration of radiant energy enables heat to penetrate the coating of paint or enamel to a depth sufficient to dry it out without wasting energy in the body of the work piece.

Advantages -
- Low investement cost of installation.
- Its high power density, resulting in very compact installations with a high heating rate.

Applications -
- food instrystory for baking.
- surface treatments (heating or drying) and pre-heating purposes.
- sintering
- metallurgy and textile industries for fixing coatings and drying paint.
- Accelerating the drying process.

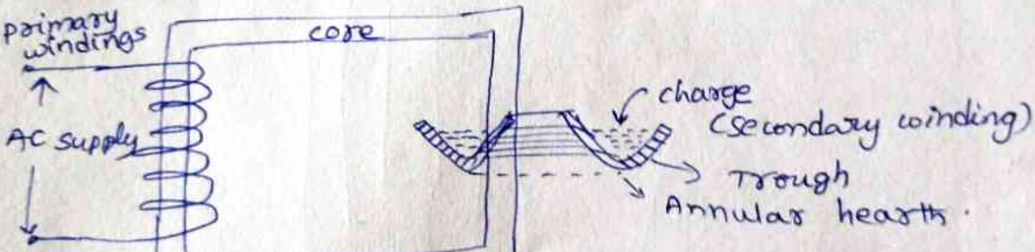
Induction Heating -
- The basic principle of induction heating is same as that of a transformer i.e it works on the principle of electromagnetic induction.
- AC current is passed through the primary winding, the coil is magnetically coupled with the metal to be heated which acts as secondary.
- An electric current is induced in this metal when AC is flown through the primary coil.
- Induction heating is also known as high frequency heating.

- The main difference b/n the conventional methods of heating and high frequency heating is that, in the former case heat is transferred either by convection, conduction or radiation while in the latter case, conversion of electromagnetic energy into heat energy takes place inside the material.
- Heat transfer by high frequency heating is as much as 10,000 $\frac{W}{cm^2}$

⇒ Induction furnaces are broadly classified as -
1) core-type (low frequency) induction furnaces
2) coreless (high frequency) induction furnaces

⇒ core type furnaces operate like a two winding transformer.
- ① Direct core type Induction furnace
- ② vertical core type induction furnace
- ③ Indirect core type induction furnace.

⇒ Direct-core-type Induction furnace -
It's 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 below.

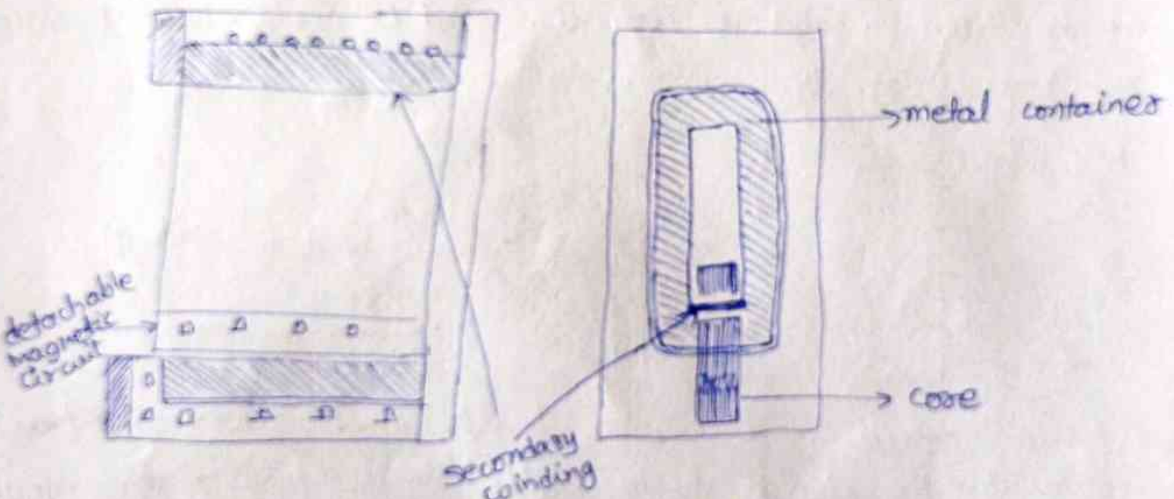


- The furnace consists of a circular hearth in the form of a trough, which contains the charge to be melted in the form of an annular ring.
- The magnetic coupling b/n primary and secondary is very poor resulting in high leakage current and a low power factor.
- It operates at a very low frequency 10 Hz.

Disadvantages -
- A crucible of inconvenient shape is required.
- low power factor due to ~~power~~ poor magnetic coupling.
- It's bulky due to the presence of a core
- at start some molten metal is necessary in the crucible

2) Indirect core type Induction furnace -

- This type of furnace is used for heat treatment of metals.
- The secondary consists of a metal container which forms the walls of the furnace.
- The primary winding is magnetically coupled to this secondary by an iron core.
- when primary winding is connected to AC 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 by radiation.
- A detachable magnetic circuit made of special alloy is kept inside the chamber.
- An alloy will lose magnetic properties at a particular temperature and are regained when it cools down.
- on reaching the critical temperature, the reluctance of the alloy increases and there by decreases induction effect.



In direct core-type induction furnace.

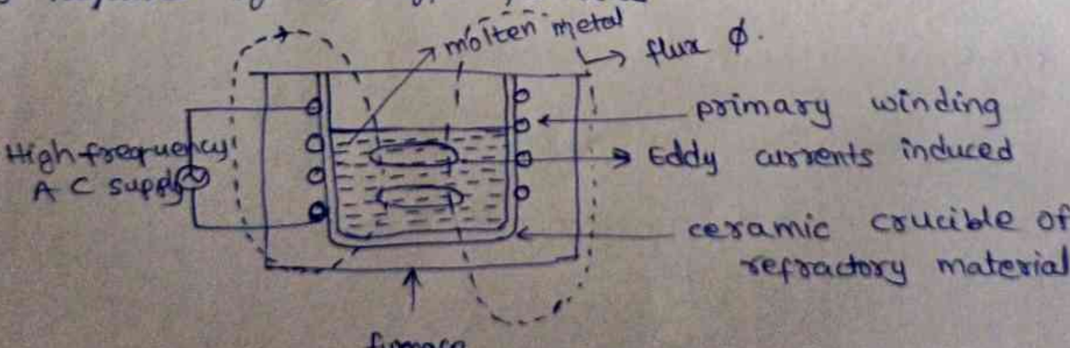
Advantages - wide variation of temperature control is possible from 400°c to 1000°c

core-less Induction Furnace - It works on the principle of an electric - transformer. as shown in the fig.

- there are three (3) main parts of the furnace are (i) primary winding (ii) ceramic crucible containg charge which forms the secondary and

(iii) the frame which includes supports and tilting mechanism.

- The important feature of this furnace is it does not contains any heavy iron core, hence the flux density will be low.
- for compensating this low flux density, the primary supply frequency should be high.
- The crucible and the coil are relatively light in construction and can be conveniently tilted for pouring.
- The charge is put into the crucible and primary winding is connected to a high-frequency AC supply.
- The flux produce by the primary sets up eddy-currents in the charge.
- These currents heats the charge to melting point and they also setup the electromagnetic force, which produces a stirring action to the charge, which is essential for obtaining uniform quality of metal.
- The charge need not be in the molten state at the start as well its required by core-type furnaces.



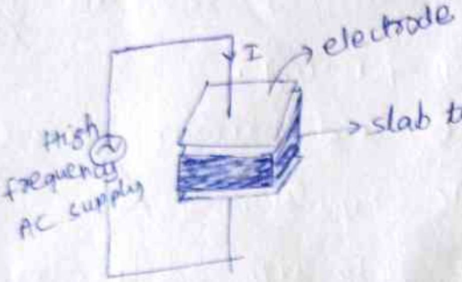
Core-less Induction furnace.

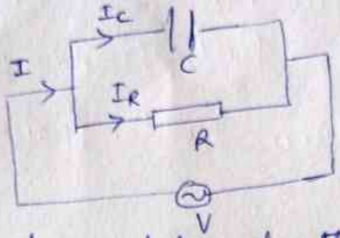
Advantages -

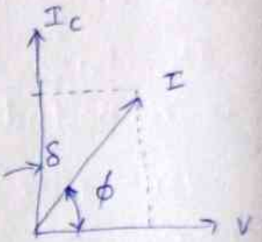
- High speed of heating
- well suited for intermittent operation
- produce high quality products
- operation is free from smoke, dirt, dust and noises
- low erection and operating costs.
- used for all industrial applications requiring heating & melting

- Dielectric Heating -

- when an insulating material such as wood, plastic, glass, ceramics, bones etc. are subjected to an alternating electric field the atoms get stressed and because of the inter-atomic friction, dielectric loss occurs which appears as heat.
- The dielectric loss dependent on the frequency and voltage.
- The insulating material to be heated is placed between two conducting plates or metallic electrodes across which a voltage is applied.







- The two electrodes acts as two plates of the capacitor and the charge acts as dielectric material b/n the two electroded.
- The material to be heated may be considered as the imperfect dielectric of a condenser and may be, therefore represented as a capacitance placed in parallel with a resistance.

current through the capacitor, $I_c = \frac{V}{X_c} = 2\pi f C V$.

the dielectric loss can be given by $P = VI\cos\phi$.

$$I_c = I\cos\delta \;;\; \phi = 90 - \delta$$

$$\therefore \quad P = \frac{V I_c}{\cos\delta}\cos(90-\delta) = V I_c \frac{\sin\delta}{\cos\delta} = V I_c \tan\delta$$

$$\therefore \quad P = V I_c \tan\delta = V \times 2\pi f C V \tan\delta = 2\pi f C V^2 \tan\delta$$

as δ is very small $\therefore \tan\delta = \delta$.

$$\therefore \quad P = 2\pi f C V^2 \delta = \omega C V^2 \delta$$

it's clear that Dielectric loss $\propto V^2$

$\propto f$

The capacitance of the condenser can be given by

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

ε_0 = absolute permittivity or dielectric constant of air $= 8.854 \times 10^{-12}$ F/m

ε_r = relative permittivity

A = surface area in 'm^2'

d = thickness of dielectric in 'm'

Advantages -

- since heat is generated with in the dielectric medium itself, it results in uniform heating.
- heating becomes faster with increasing frequency.
- heating can be stopped immediately as and when desired.
- materials heated by this method are combustible which cannot be heated by flame.
- heating of non-conducting (i.e non metallic) materials is very speedy

Applications -

- drying tobacco, paper and rayon, wood.
- welding of PVC
- stress annealing textile fibers
- heating of bones and tissues
- Gluing and bonding of wood.
- sterilization of cereals and medical equipment.
- sewing of rain coats, umberellas made of plastic film materials
- In diathermy for relieving pain in different parts of human body.

⇒ Difference b/n Induction Heating and Dielectric Heating -

S.No	Induction Heating	Dielectric Heating
①	It's caused by eddy currents in Imperfect dielectric	It depends on the electrostatic effect.
②	The operating frequencies are in the range of 1200 to 500 KHz	The operating frequencies are in the range of 1 to 50 MHz.
③	It's also termed as surface Heating	It's also called volume heating.
④	Equipment cost is low	Equipment cost is comparatively High
⑤	Applications - foundries for melting & refining brass, zinc, steel production, carbon alloys, ferrous alloys etc.	Applications - preheating of plastic, gluing of wood, baking of foundry cores, diathermy, textile industry, food processing etc.