Utilization of Electrical Energy

Course Topics (Code- EE 444)

- Illumination
- Electric Wielding
- Electric Heating
- Electrolytic Processes
- Refrigeration & Air Conditioning
- Electric Traction

ELECTRIC HEATING

- Power Frequency/Ohmic Heating method (50-60 Hz)
  - Resistance Heating
    1) Direct
    2) Indirect
  - Arc Heating
    1) Direct
    2) Indirect
- High Frequencymethod /Radio Frequency (kHz) (5-500KHz)
  - Induction Heating
    1) Direct
    2) Indirect
  - Dielectric Heating/ High Frequency Capacitive Heating
  - Infrared / Radiant / Radiant Heating
- Microwave Heating (0.3 GHz ±300 GHz)

WHAT IS ELECTRIC HEATING & its principle?

Electric heating is any process in which ELECTRICAL ENERGY is converted to "**HEAT ENERGY".**

Electric heating works on the principle of "**JOULE HEATING"** (an electric current through a resistor converts electrical energy into heat energy.)

For material which has resistance 'R' ohms and current flow in it is I amps for 't' seconds then Electrical energy is converted into heat energy

$$H = I^2R \times t \text{ Joules}$$

$$\text{Power loss} = I^2R \text{ watts}$$

$$= VI \text{ Watts}$$

$$= V^2/R \text{ watt}$$

INDUSTRIAL APPLICATION

- Melting of metals
- Electric welding
- Mouldling of glass for making glass appliances
- Baking of insulator
- Mould ling of plastic components
- Heat treatment of pointed surpasses
- Making of plywood.

TRANSFER OF HEAT – in conventional heating

Conduction:

This phenomenon takes place in solid, liquid and gas. Heat transfer is proportional to the difference of temperatures between two faces.
No actual motion of molecules.

Convection

This phenomenon takes place in liquid and gas. Heat is transferred due to actual motion of molecules

Radiation

This phenomenon is confined to surfaces. Radiant energy emitted or absorbed is dependent on the nature of the surface.

Conventional heating vs. electro heating

- The Conventional heating methods involves conduction, convection and radiation heat transfer. In conventional heating at higher temperature the product is hot and can dry outside leading to relatively cold and wet inside surface and this cannot considered efficient because the dry outer layer acts as an insulating barrier and reduces the conduction heat transfer giving produce less quality and shelf life attributes.

- In contrast electro heating (e.g. Ohm, µW and RF) generates heat volumetrically within the material by either alternating electrical current (as in Ohm) or *electromagnetic radiation µW (300–3000 MHz) or RF (1–300 MHz) frequencies.*

- *Electro heating can be sub-divided into either <u>direct electro heating</u> where electrical current is applied directly to the food (e.g. ohmic heating (Ohm)) or <u>indirect electro heating</u> (e.g. microwave (µW) or radio frequency (RF) heating) where the electrical energy is firstly converted to electromagnetic radiation which subsequently generates heat within the product.*

Classification of Heating Method:-

Low Temperature Heating	**up to 400°C**
Medium Temperature Heating	**400°C to 1150 °C**
High Temperature Heating	**above 1150 °C**

Characteristics of Heating Elements

1) High resistivity

2) Able to withstand high temperatures without deterioration

3) Low temperature coefficient of resistance

4) Positive temperature coefficient of resistance

5) Free from oxidation at high temperatures

Direct Resistance Heating

- Fig.1 shows direct resistance heating
- In this method of heating, current is passed through the material or charge to be heated
- Charge is considered in a furnace and two electrodes or three electrodes for 3phase are immersed in the charge

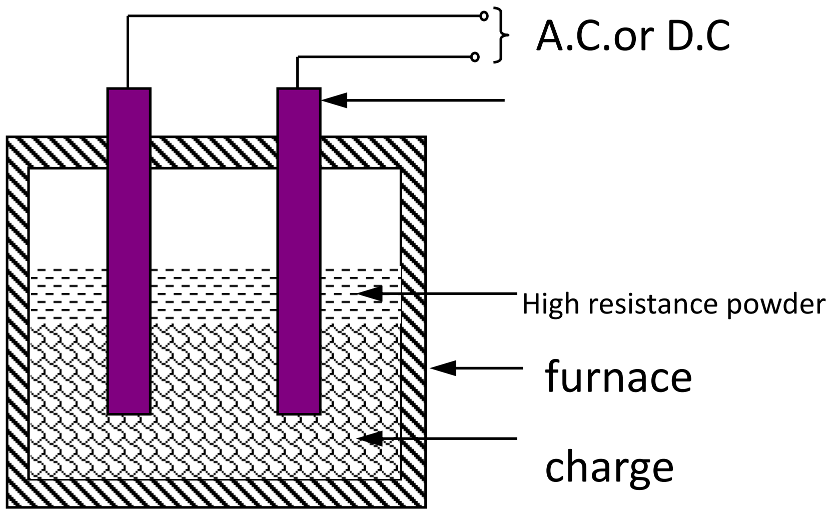
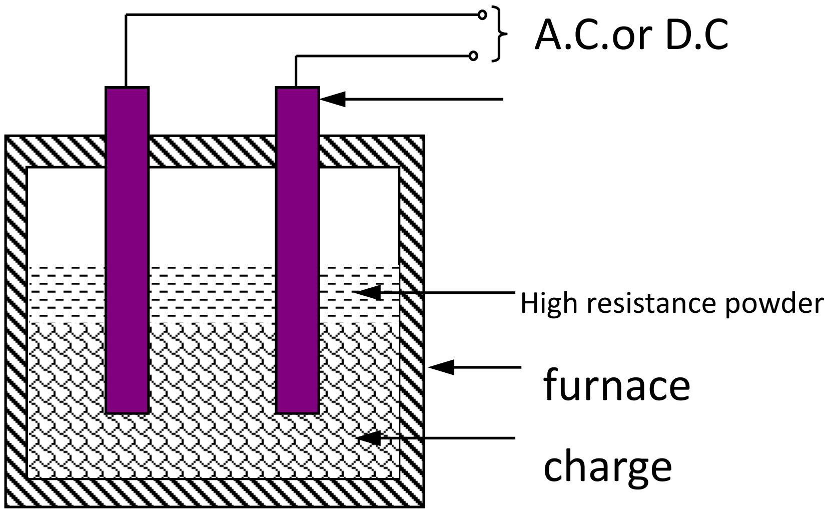


Fig.1

Direct Resistance Heating

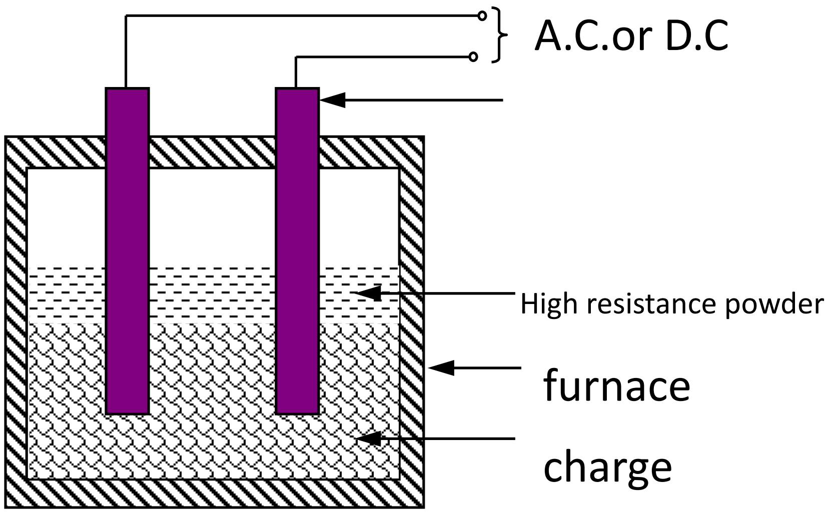
- The resistance offered by the charge to the flow of current causes power loss I^2R and it results in the heating of the charge

- The charge may be in the form of solid pieces, powder or liquid



Direct Resistance Heating

- When solid pieces are to be heated a powder of high resistivity material is sprinkled over surface of charge.
- This is to avoid pinch effect
- The current passes through the charge and heat is produced



Applications

This method of heating is used in

- Resistance welding
- The electrode boiler for heating water
- Salt bath furnace which is used for hardening steel tools and prevents oxidation

Indirect Resistance Heating

- Fig.2 shows indirect resistance heating
- In this method of heating, current is passed through a high resistance wire known as heating element
- The heating element can be placed above or below the furnace/charge

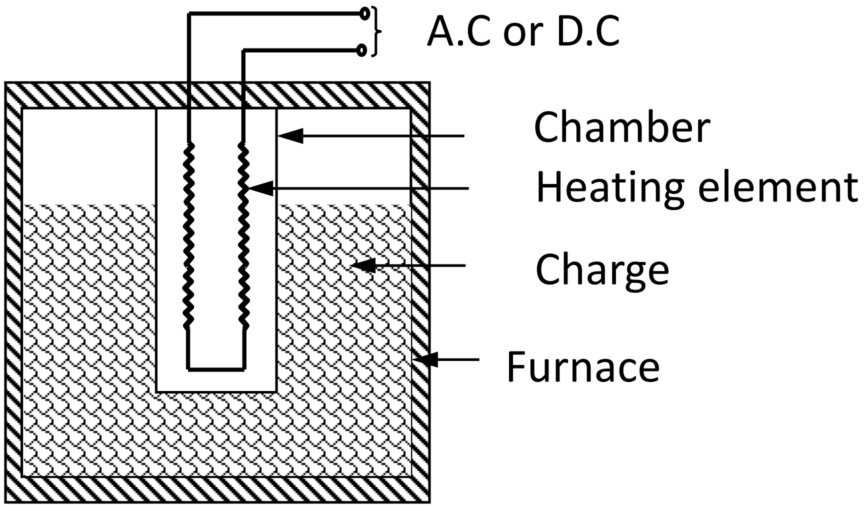
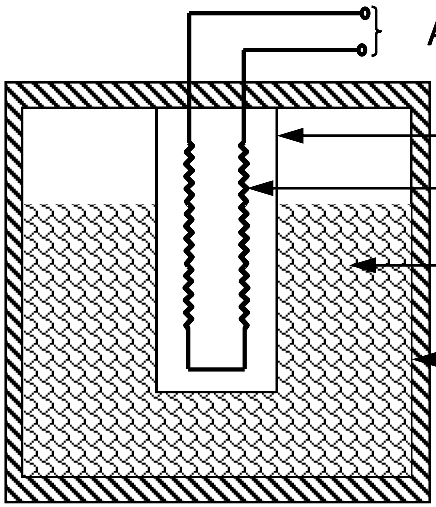


Fig.2

Indirect Resistance Heating

- Charge will enclose the heating element for efficient heat transfer

- The heat produced in the element is transferred to the charge by radiation or convection methods



Application

This method of heating is used in

- Room heaters
- Bimetallic strip used in starters
- Water heater i.e. immersion heater
- Ovens like domestic cooking
- Salt bath furnace

Dielectric Heating

Dielectric material:

- **Dielectric material is of** low heat conductivity and used as insulating material. It is difficult to heat such materials quickly and uniformly by the external application of heat without subjecting the outer layers of the material to high temperatures as to impair their physical properties.

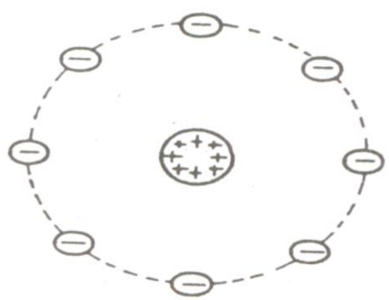
- Commonly used dielectrics:
  Solids - Rubber, glass, wood and polymers;
  Liquids- Hydrcarbon oils and silicone oils.

- Such materials is heated by means of the dielectric loss produced in them when they are subjected to a **high voltage, high frequency field**.

Dielectric Heating

- **Dielectric loss:**

When an insulating material is subjected to an alternating electric field, the atoms get stressed and, due to inter-atomic friction caused by repeated deformation and rotation of atomic structure , heat is produced. This loss is known as dielectric loss.



➢ The dielectric loss is dependent upon the frequency and high voltage: voltage at 20kV and above & frequencies in the range of 10 to 30 Mega cycles per second.

Dielectric & Hysteresis Losses

- Hysteresis loss is due to the reversal of magnetism or magnetic molecular friction which appears as heat.

- **During each A.C. cycle, current flowing in the forward and reverse directions magnetizes and demagnetizes the core alternatively. Energy is lost in each hysteresis cycle within the magnetic core. Energy loss is dependent on the properties (e.g. coercivity) of particular core material and is proportional to the area of the hysteresis loop (B-H curve).**

Dielectric Heating

- Electrically every atom is neutral, since the central positive charge equals the surrounding negative charge.

- The centers of positive charge and negative charge are co-incident as long as there is no external electrical field (fig. 3)

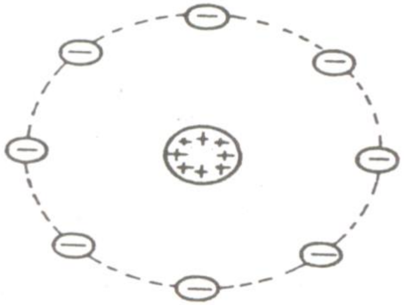


Fig.3 Neutral Atom

Dielectric Heating

- When atom is subjected to some external electric fields Positive charge of nucleus is acted upon by some force in the direction of the field & Negative charge in the opposite direction.

- The effective centers of positive and negative charges are no longer coincident i.e., POLARIZED as shown in fig. 4.

Dielectric Heating

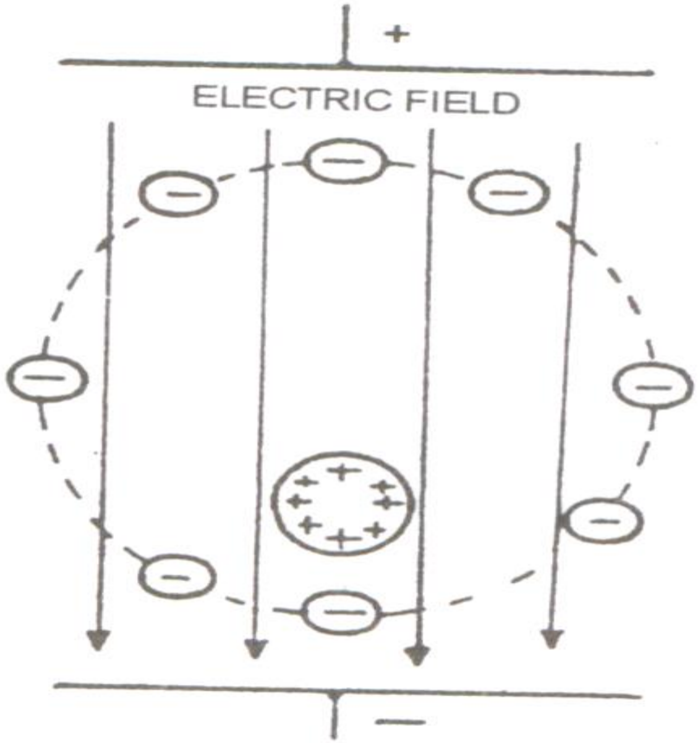


Fig.4 **POLARIZED**

Dielectric Heating

- This is known as electric dipole moment

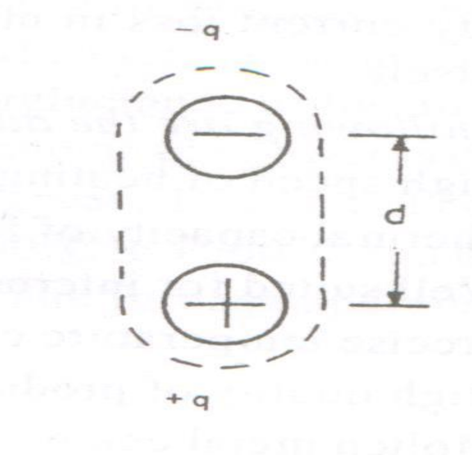


Fig.5

$p = q\,d.$

where q = charge on the nucleus (coulomb)

d = distance between the two centres (m)

- **The atom in this state is said to be polarized**

Dielectric Heating

- when the electric field strength is increased, the degree of polarization also increases.

- After attaining a certain value of electric field, all the electric dipoles of a dielectric material will align themselves shown in fig 6

Dielectric Heating

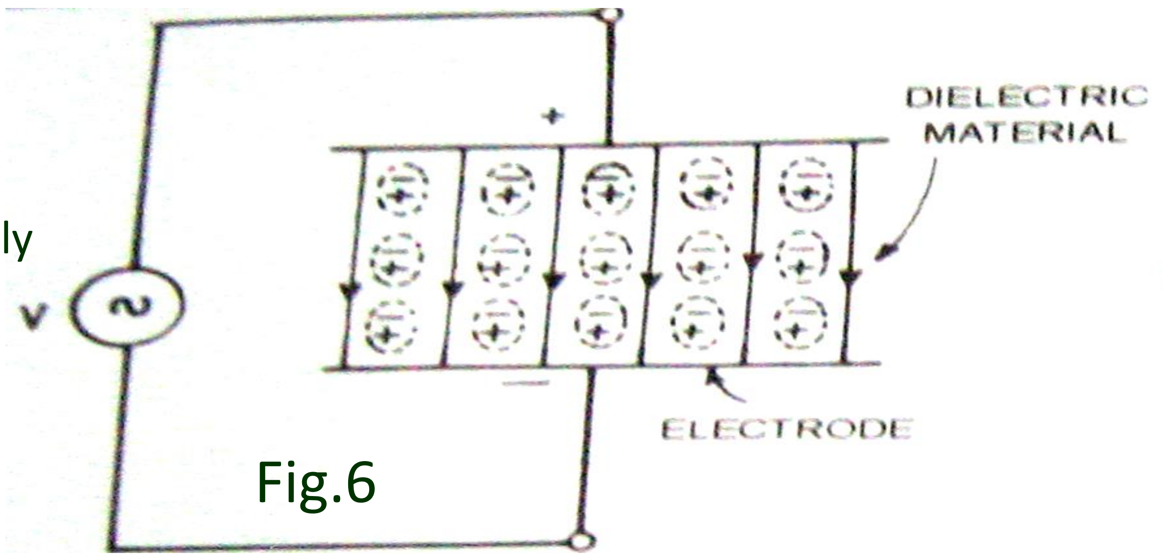


Fig.6

- The orientation of electric dipole will try to change according to the electric field applied.

- **Some of the energy wasted towards the inter atomic friction is called the dielectric loss.**

Dielectric Heating

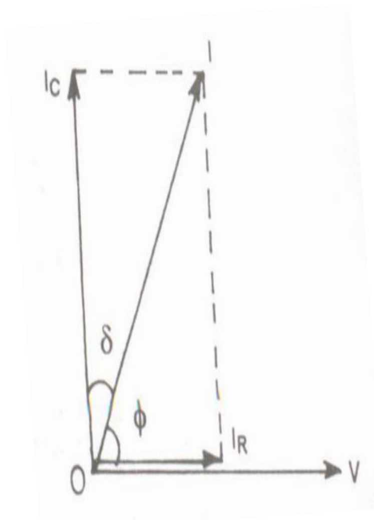
- The loss increases with increase in frequency and strength of the electric field
- **Dielectric loss taking place in insulating material is analogous to hysteresis loss.** This loss takes place in a ferro-magnetic material.
- Hence it is also known as **dielectric hysteresis**

Dielectric Heating

- As far as possible no air-gap should be left over between the electrode and material to be heated
- The dielectric strength of air is smaller than any dielectric material
- If voltage applied across the electrodes with air-gap and dielectric, **air gets ionized first and result into the break down**

Dielectric Heating

- Therefore, it is desirable in dielectric heating not to apply high voltage but to use high frequencies.
- All dielectric materials can be represented by a parallel combination of a leakage resistor ‘R’ and a capacitor ‘C’ shown in fig. 7



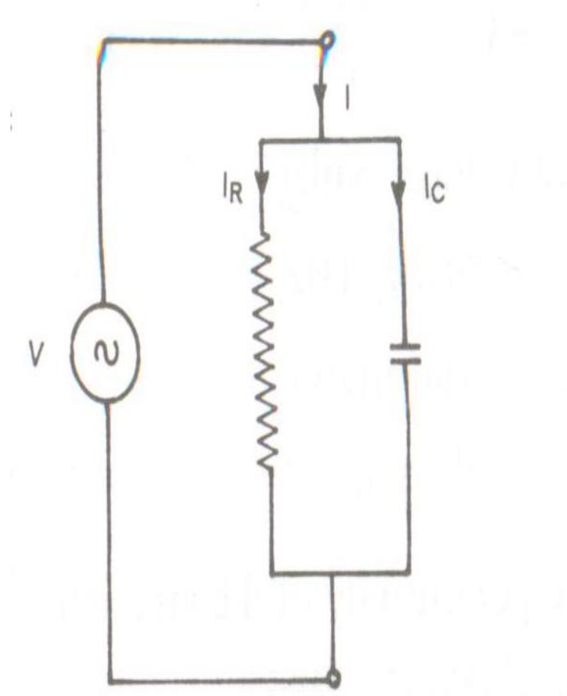


Fig.7

Derivation of Dielectric loss

Dielectric loss = $V\,I\,\cos\Phi$

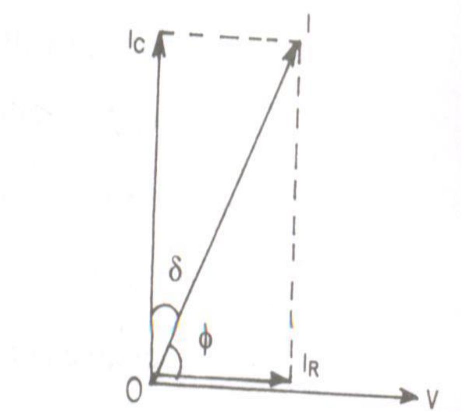
From fig 6 $= V\,I_R$

$= V\,I_c \tan\delta$

$= V\,[\,V / x_c\,] \tan\delta$

$= V^2 \omega\, C \tan\delta \;(\tan\delta \approx \delta)$

$$= \frac{V^2 \times 2\pi f \times \epsilon_o \epsilon_r A \times \delta}{d} \text{ watt.}$$



Dielectric loss

Where, v	=	Applied voltage (V)
f	=	Supply frequency (Hz)
C	=	Capacitance (F)
$\in_o$	=	Absolute permittivity 8.854×10^{-12} F/m.
$\in r$	=	Relative permittivity of the medium
	=	1 for free – space

Dielectric loss

A = Area of the plate or electrode (m^2)

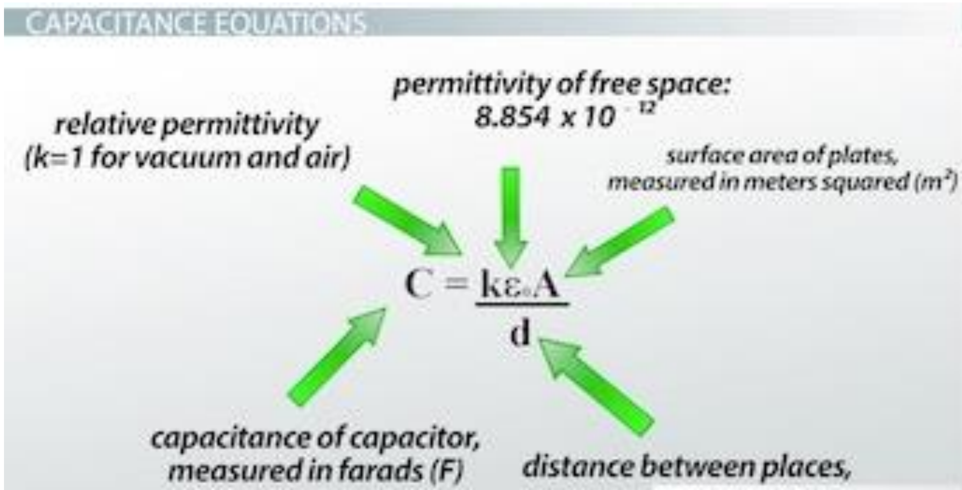
d = Thickness of dielectric medium or distance between electrode (m).

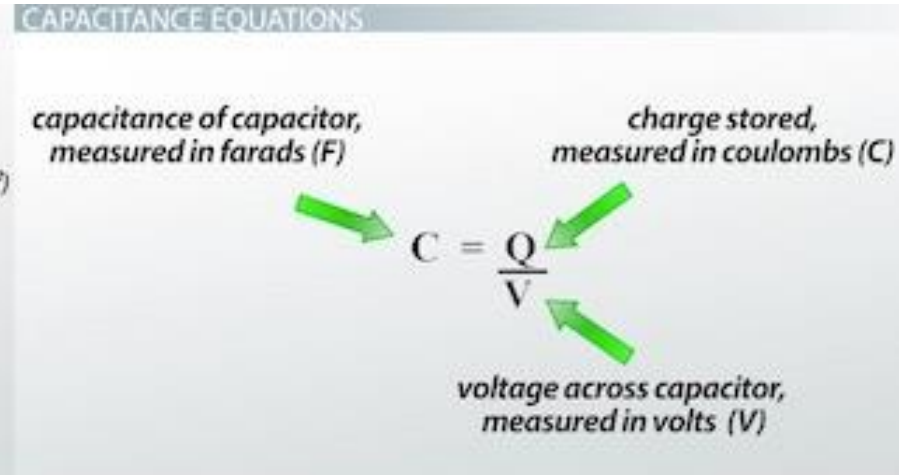
δ = **Loss angle (radian).**

$\in_r \delta$ = **Loss factor.**

From the above equation, the dielectric loss

$$\mathbf{P \propto V^2 \quad and \quad P \propto f}$$





In electrostatics, **permittivity** is a measure of how much energy is required to establish an electric field in a dielectric material.

Dielectric loss

- The use of high voltage is limited due to break down voltage of the thin dielectric which is to be heated.
- Under normal conditions, voltage gradient used is limited to 18 kV/cm
- The choice of frequency depends on the loss factor of the dielectric.

Dielectric loss

- Higher frequencies are used for low loss factor dielectric and vice-versa
- Dielectrics having loss factor less than 0.05 are not economical to be heated by this method.
- **Frequency used for dielectric heating is the range of 10MHz to 40 MHz.**
- **Though voltages upto 20kV have been used but from safety point of view voltages between 600V to 3000V are more common.**

Applications of Dielectric Heating

1. **Drying tobacco, paper, wood and rayon**
2. **Welding of PVC**
3. **Stress annealing textile fibers**
4. **Heating of bones and tissues**
5. **Gluing and bonding of woods**
6. **Sterilization of cereals and medical equipment**
7. **Processing of rubber synthetic materials and chemicals during manufacture……………………….contd.**

Applications of Dielectric Heating

8. **Heat-sealing of plastic resins**

9. **Preparation of thermo plastic resins**

10. **Sewing of rain coats, umbrellas made of plastic film materials**

11. **Diathermy treatment of certain body pains and diseases etc**

Advantages of Dielectric Heating

1. **Heat is produced in the whole mass of the material**

2. **Heating non-conducting materials is very speedy**

3. **Uniform heating**

4. **Materials heated by this method are combustible which cannot be heated by flame**

Induction Heating

Physics of induction Heating

The phenomenon of Induction heating involves two different types of **physics: electromagnetism and heat transfer**, and these two physical phenomena are coupled.

Heating takes place **without physical contact between the work-piece and induction coil.** The material to be heated, known as the *work-piece*, is placed inside the magnetic field, without touching the coil.

By applying a high-frequency AC current to an induction coil, a time-varying magnetic field is generated.

The combination of the coil and work piece can be **considered like a transformer**, with the **coil acting as the primary being fed with electrical energy, and work piece as the short circuited secondary**.

Physics of induction Heating

The alternating electromagnetic field **induces enormous currents called eddy currents in the workpiece**, resulting in resistive losses, which then heat the material up.

Eddy current loss + hysteresis loss that depend upon the magnetic properties of the material) = core losses or iron losses (whereas ohmic/resistive loss in the primary & secondary windings is cupper loss).

Eddy currents induced within the workpiece will primarily flow in the surface layer (the "skin"), where 86% of all induced power will be concentrated. This layer is called the reference depth or current penetration depth, δ.

- **Hysteresis loss in transformer** can be given by,

$$W_h = \eta B_m^{1.6} f V \text{ (watts)}$$

where, f= frequency (Hz)

η = Steinmetz hysteresis constant (J/m^3)

V = volume of the core in m^3

B_m =is the maximum flux density of the core (wb/m^2).

- **Copper loss** is due to ohmic resistance of the transformer windings. Copper loss for the primary winding is $I_1^2R_1$ and for secondary winding is $I_2^2R_2$

Eddy current loss in thin material:

$$W_e = K_e * B_{max}^2 * f^2 * t^2 * V$$

Where,

P_e = eddy current loss (W)

K_e = eddy current constant

B = flux density (Wb/m^2)

f = frequency of magnetic reversals per second (Hz)

t = material thickness (m)

V = volume (m^3)

Physics of induction Heating

Eddy currents induced within the workpiece primarily flows in the surface layer (the "skin"), where 86% of all induced power will be concentrated. This layer is called the reference depth or current penetration depth, δ.

Thus, **skin effect** is the tendency of an alternating electric current (AC) to become distributed within a conductor such that the current density is largest near the surface of the conductor, and decreases with greater depths in the conductor. It is due to opposing eddy currents induced by the changing magnetic field resulting from the alternating current.

For example, the effective resistance of the conductor to increase at higher frequencies. At 60 Hz in copper, the skin depth is about 8.5 mm. At high frequencies the skin depth becomes much smaller. This, in turn, leads to an increased resistance of the conductor, ultimately resulting in a greatly increased heating effect.

.

Physics of induction Heating

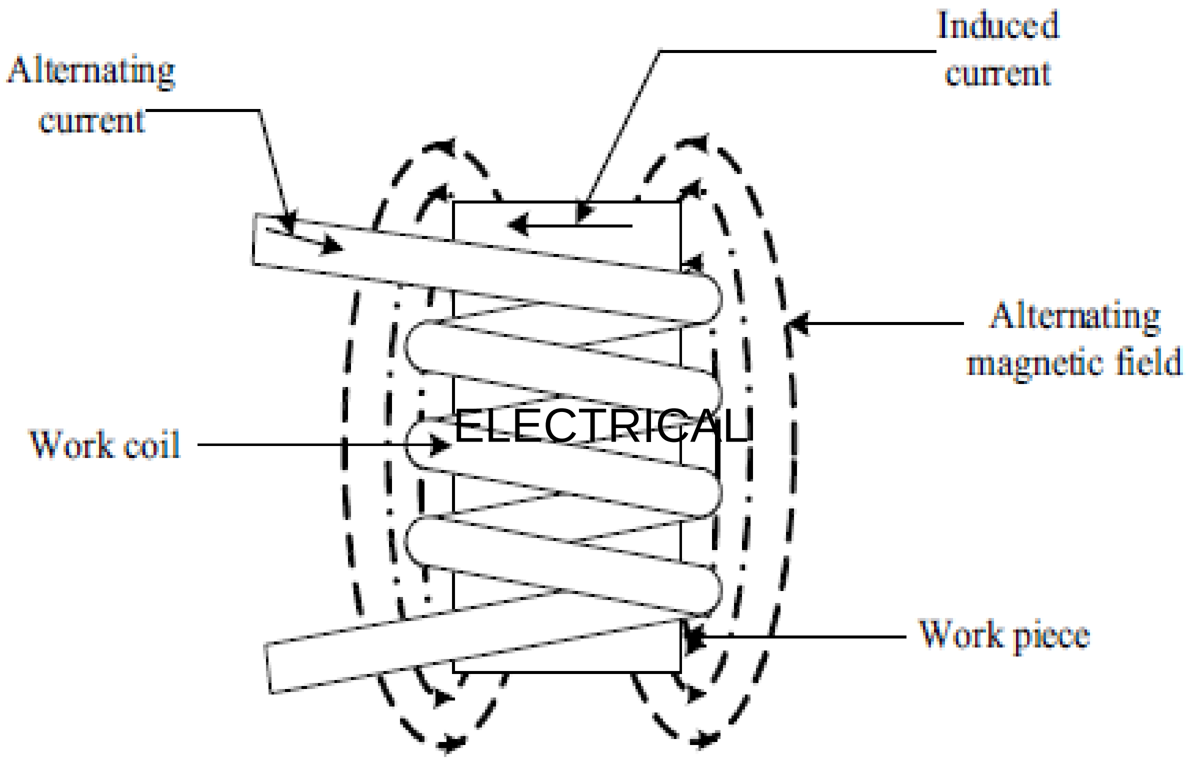
- Electrons have a property called spin, behaving like a tiny magnet pointing in a specific direction. Electrons spin on one direction (called up) or the other, called down.

- Ferromagnetic materials have an unbalanced set of electrons, having more up-spin electrons than down ones in each atom, or vice versa; influenced by magnetic fields and behave like a tiny magnet.

- Ferrous metals and materials that have high electrical conductivity (such as copper, gold, and aluminium, to name a few) are heated by induction more easily than other materials.

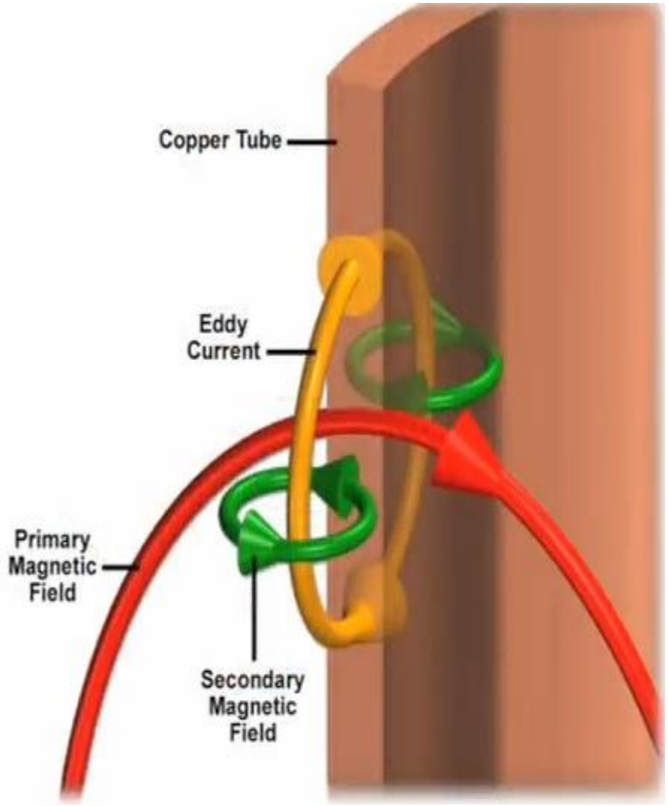
- **Non-ferrous materials like zinc and tin and most non-metals have a balanced set of electrons, where every up-spin electron is matched to a down-spin one. The magnetic field only creates very small <u>eddy currents that aren't enough to heat things up.</u>**

What is Induction Heating?

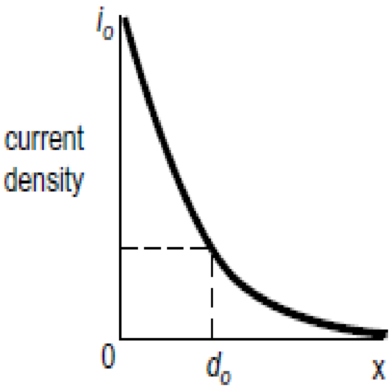


Background for Induction Heating

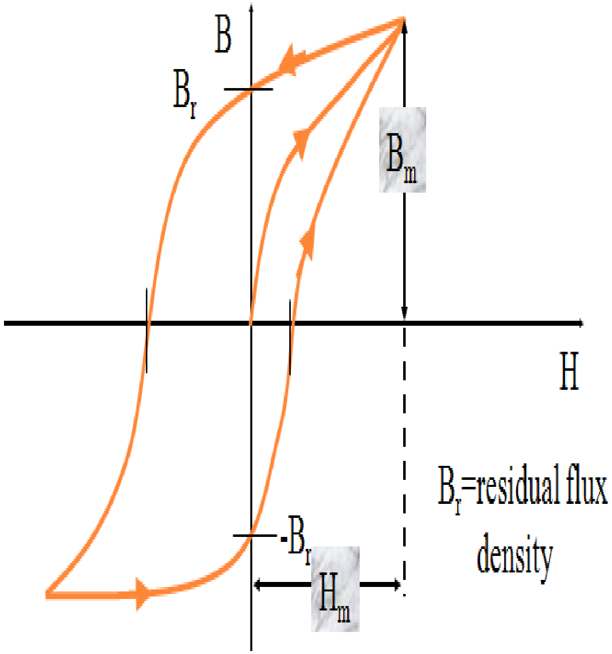
Eddy Current

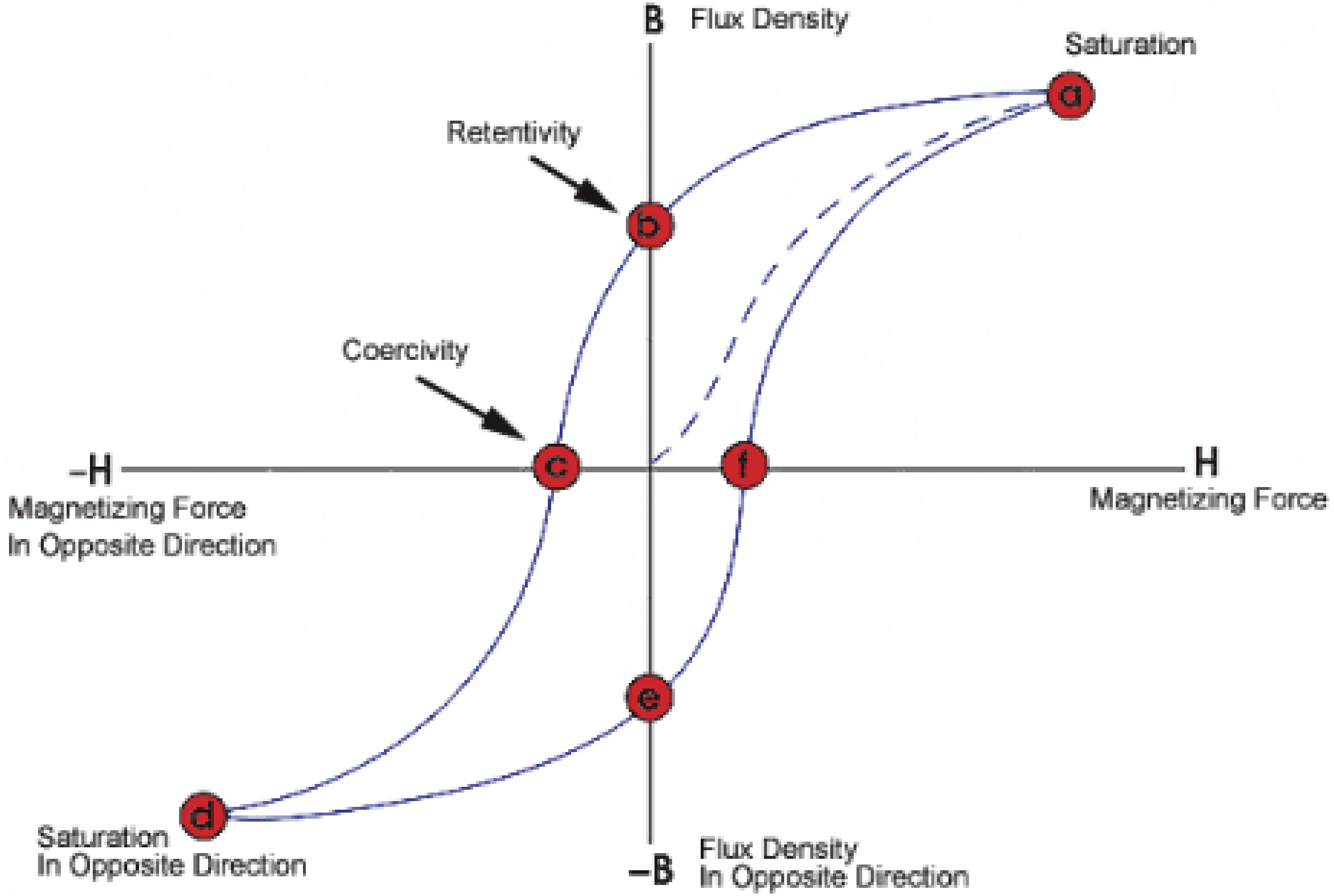


Skin Effect



Ferromagnaric Material




B Flux Density
Saturation
Retentivity
Coercivity
a
b
c
d
e
f
–H
Magnetizing Force
In Opposite Direction
H
Magnetizing Force
Saturation
In Opposite Direction
–B
Flux Density
In Opposite Direction

B-H loop.

The penetration depth is defined as the point where RF electric current decreases to about 37% (1/e =1/2.718=0.368; e is the base of natural logarithm) compared with the current at the surface and normally expressed as δ . In Fig.-2, the penetration depth is shown as the points, which are the cross points of line A with the current penetration curves. The penetration depth δ is calculated as follows.

$$\delta = 5.03 \times \sqrt{\frac{\rho}{\mu f}} \text{ (cm)}$$

δ = penetration depth (cm)

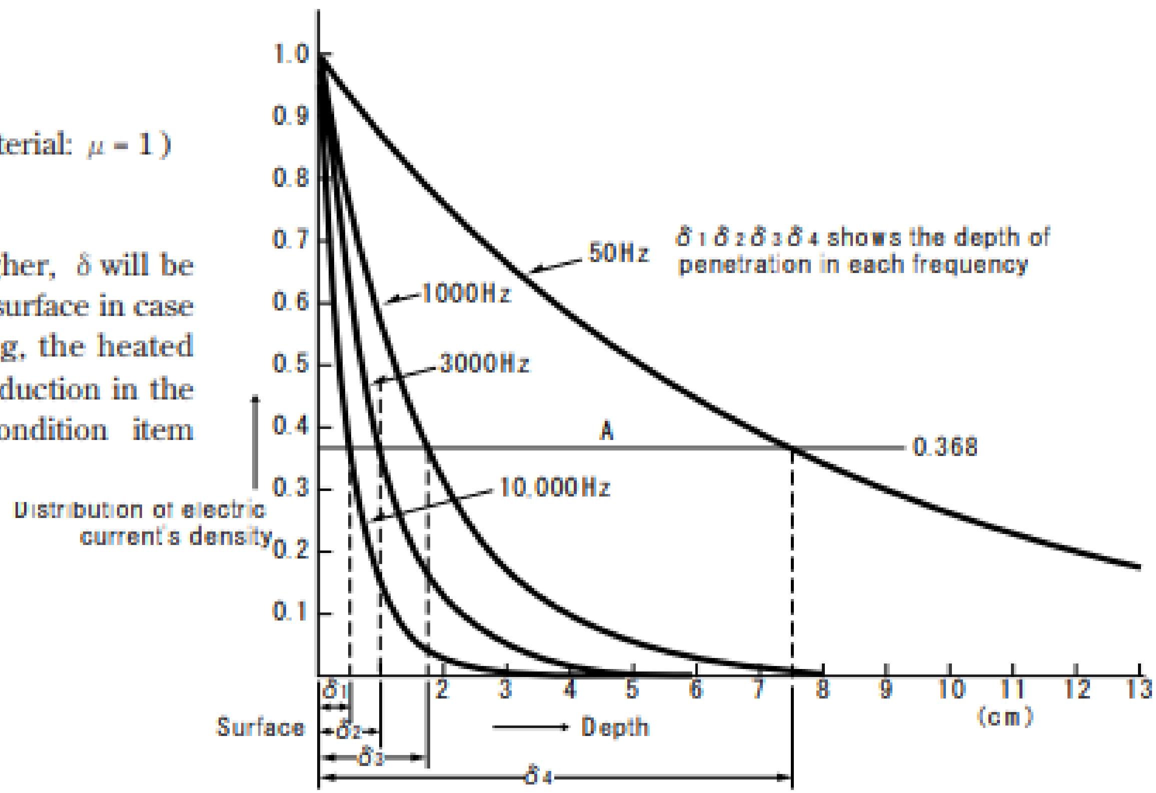
μ = specific permeability

(magnetic material: $\mu > 1$, non-magnetic material: $\mu = 1$)

f = frequency (Hz)

ρ = specific resistance ($\mu\Omega \cdot$ cm)

This formula shows that as the frequency is higher, δ will be smaller and the heating will be concentrated at the surface in case the materials are same. However in actual heating, the heated depth tends to become bigger because of heat conduction in the heated material. (Refer to Setting of Hardening Condition item (3) Choice of frequency)



Induction Heating

Thus, heat in the workpiece can be increased by

1. High coil current
2. Larger no. of coil turns
3. High frequency supply
4. Close spacing between the coil and workpiece
5. The disc may be magnetic material of high permeability
6. Higher electrical resistivity of the workpiece.

Induction Heating

Effect of Frequency on Induction Heating

- Frequency range is determined by the dimensions of the work piece, type of material, arrangement between the object and the coil, and the desired depth of penetration.

- Transfer of energy is the most during the process at high frequency, when the depth of current penetration is low; as the frequency is increased, the penetration of heat is decreased.

- The normal range of frequency is 500 Hz to 10 kHz, known as medium frequency, and 100 kHz to 2 MHz, called high range.

- Frequencies in the range of 100 to 450 kHz create comparatively high energy heat that is suitable for rapid heating of small objects.

- When deep penetration of heat is required, extensive cycles of heating at low frequency are essential, frequency range being 5-30 kHz.

Induction Heating

Induction furnaces are further classified as

i) Core type induction furnace

ii) Coreless induction furnace

Core Type Induction Heating

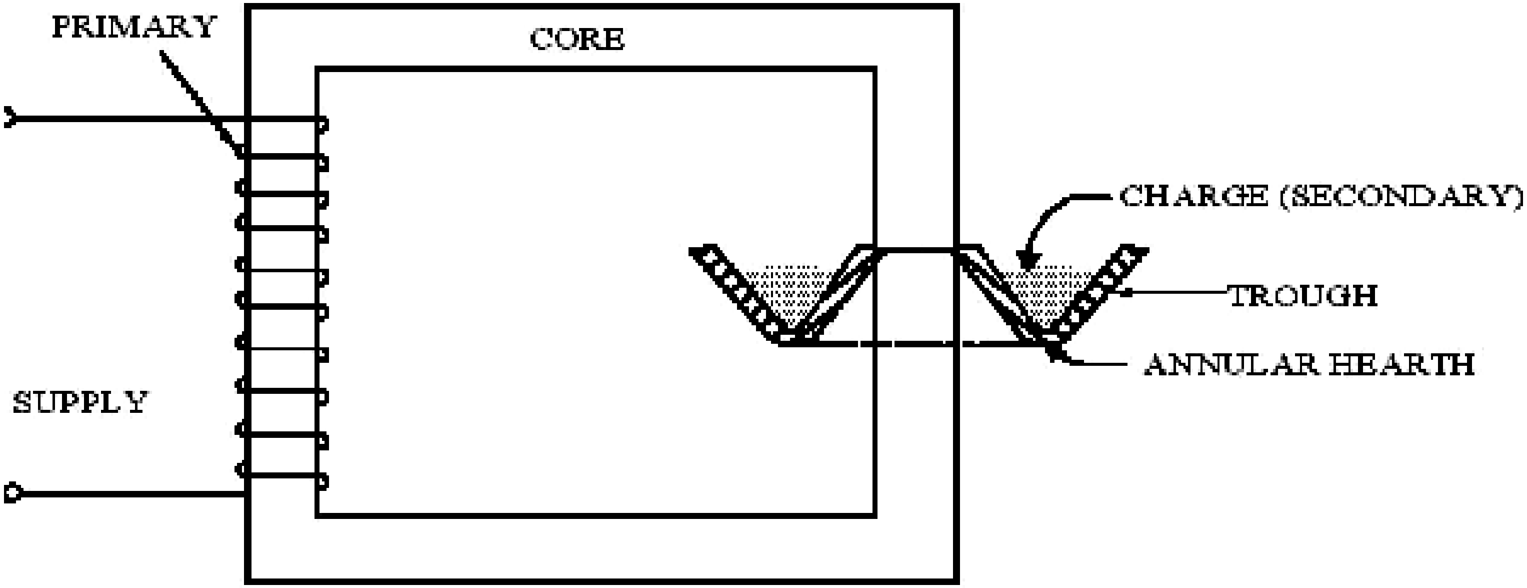
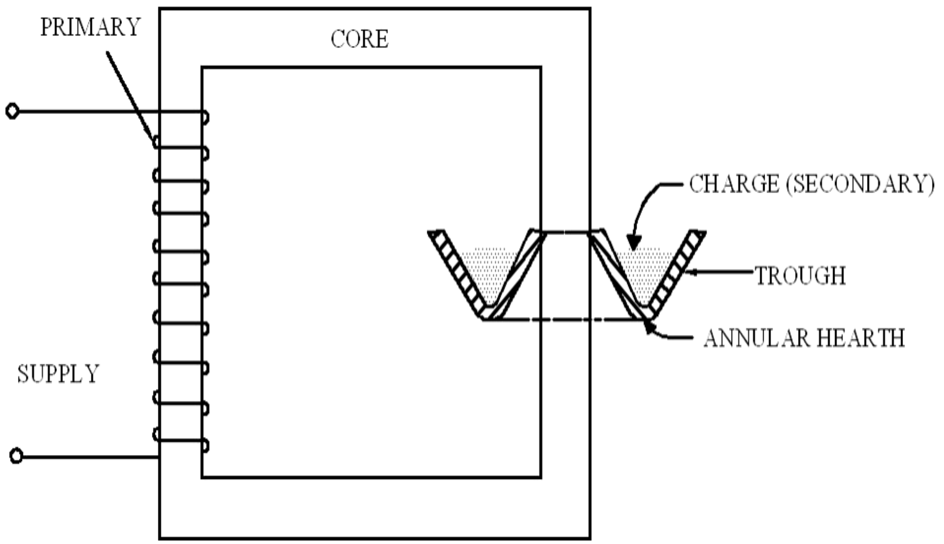


Fig.

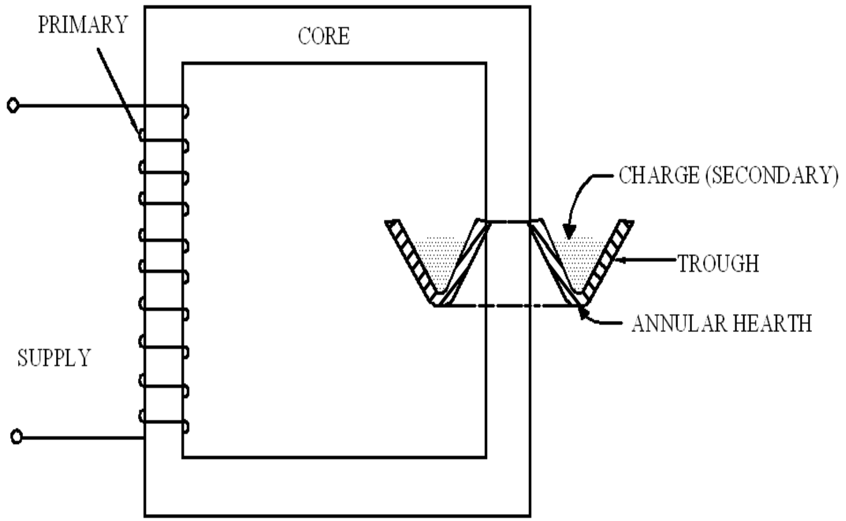
Core Type Induction Heating

- Fig shows a core type induction surface
- The Core type furnace is essentially a transformer
- Primary side is connected to supply
- Secondary side contains charge (materials) in iron core annular hearth



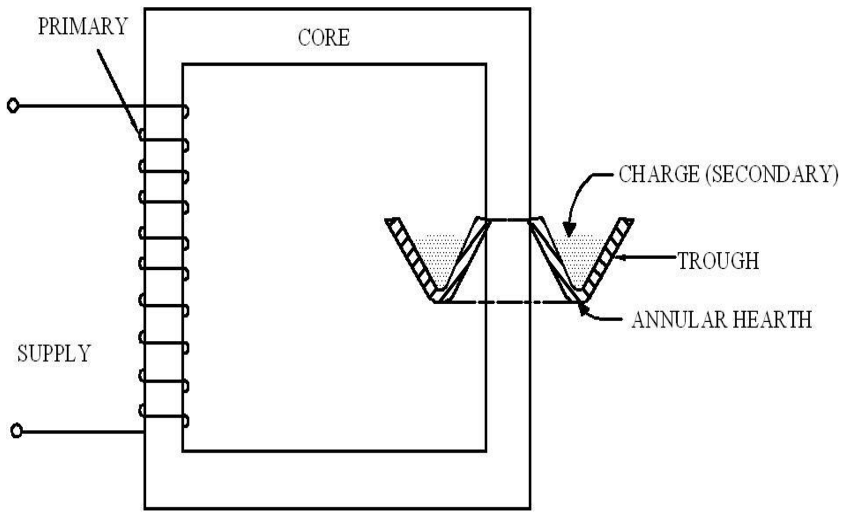
Core Type Induction Heating

- The charge is magnetically coupled to the primary by an iron core
- The magnetic coupling between primary and secondary is very poor resulting in high leakage current and a low power factor. For this reason the furnace is operated at low frequencies of the order of 10Hz or so



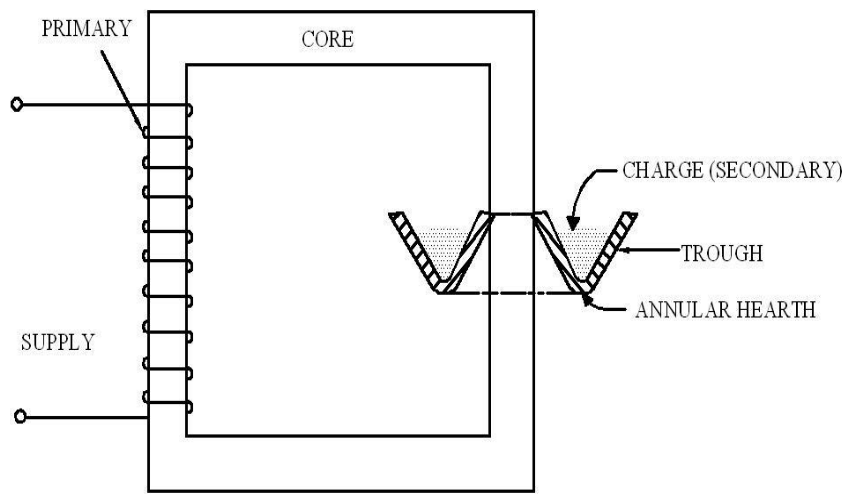
Core Type Induction Heating

- Hence it is called low frequency furnace i.e., 10Hz
- The low frequency necessitates an additional motor-generator set or frequency converter
- To start the furnace molten metal is poured in the annular hearth before start



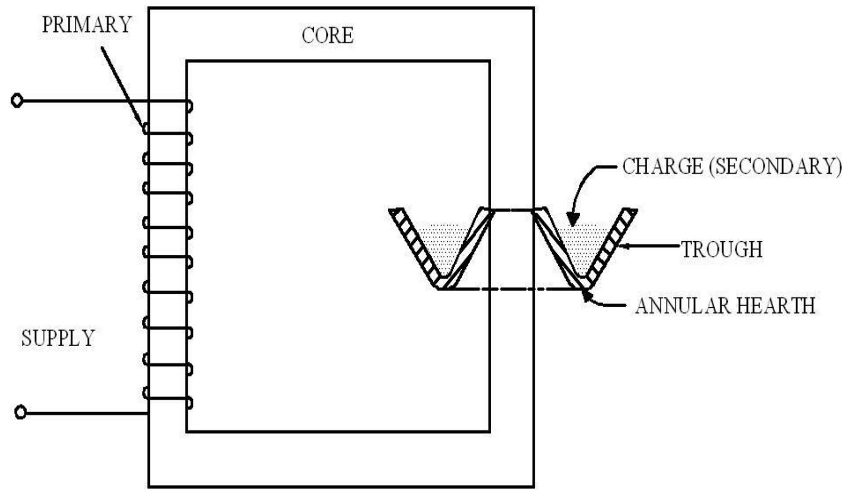
Core Type Induction Heating

- Otherwise there is no material and the secondary side is open and no current will be induced
- Hence no heating will take place
- This is convenient where the furnace is to be used for melting different types of charges



Core Type Induction Heating

- If the current density exceeds about $5A/mm^2$ the pinch effect due to electro magnetic forces, may cause a complete interruption of the secondary circuit



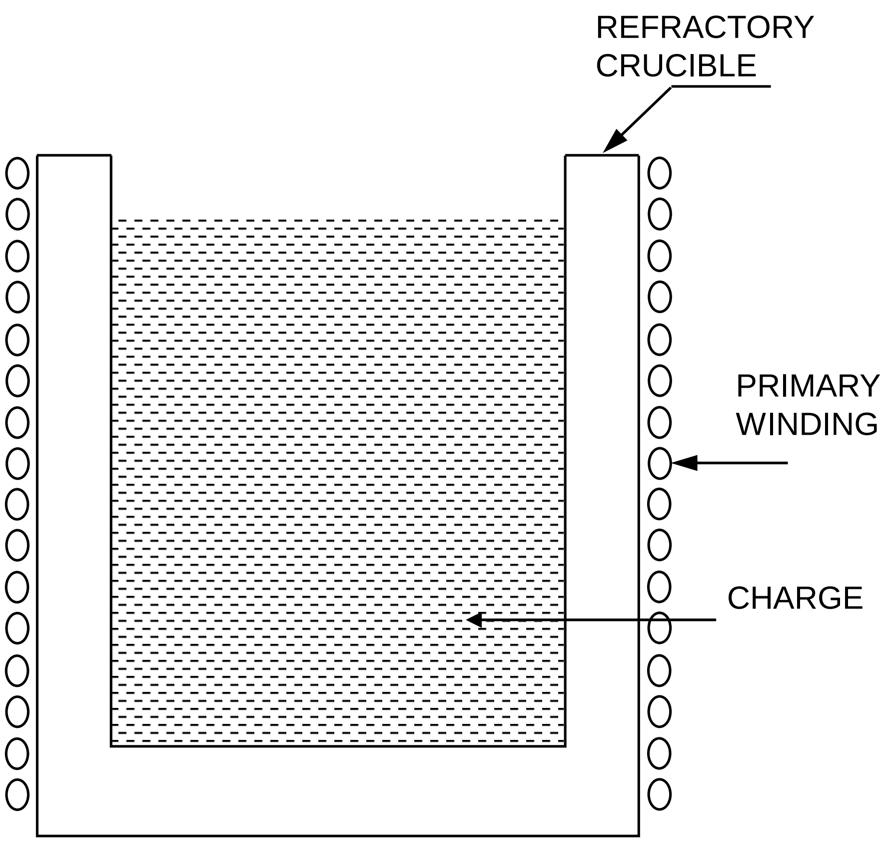
Core Type Induction Heating

Disadvantages

- A crucible of inconvenient shape is required (crucible is a ceramic or metal container in which metals or other substances may be melted or subjected to very high temperatures.)
- Low power factor due to poor magnetic coupling betn. primary and secondary
- Frequency converter is required
- It is bulky due to the presence of core

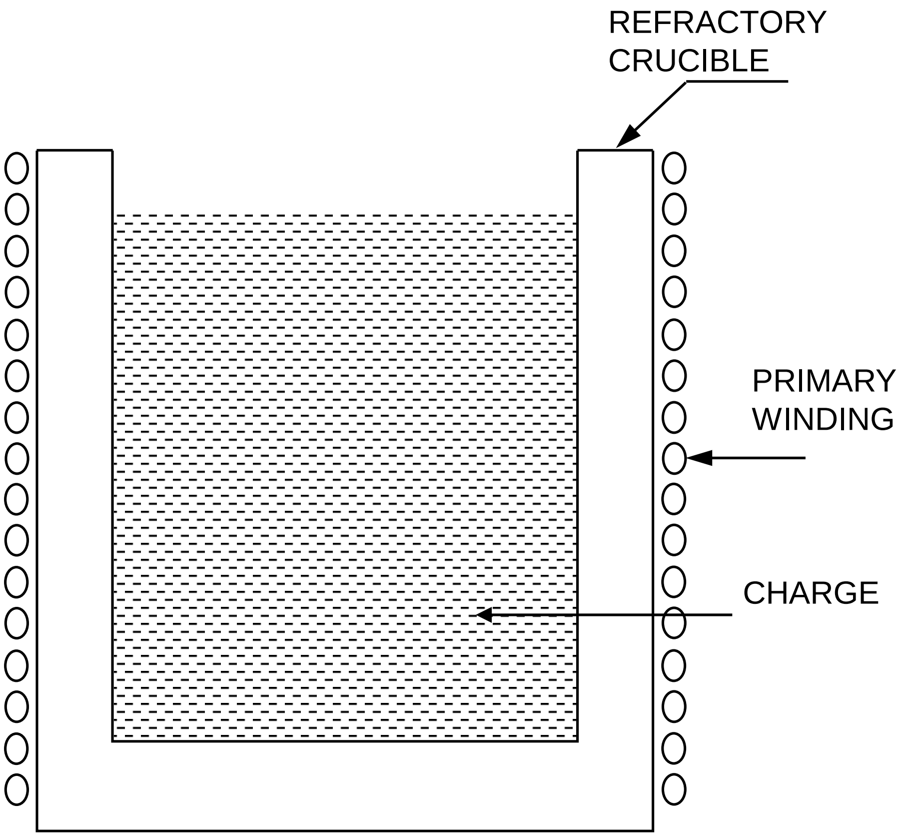
Coreless Induction Heating

- The coreless induction furnace operates on the principle of an electric transformer
- If there is no core, the flux density will be low
- For compensating the low flux density, the primary supply should have high frequency



Coreless Induction Heating

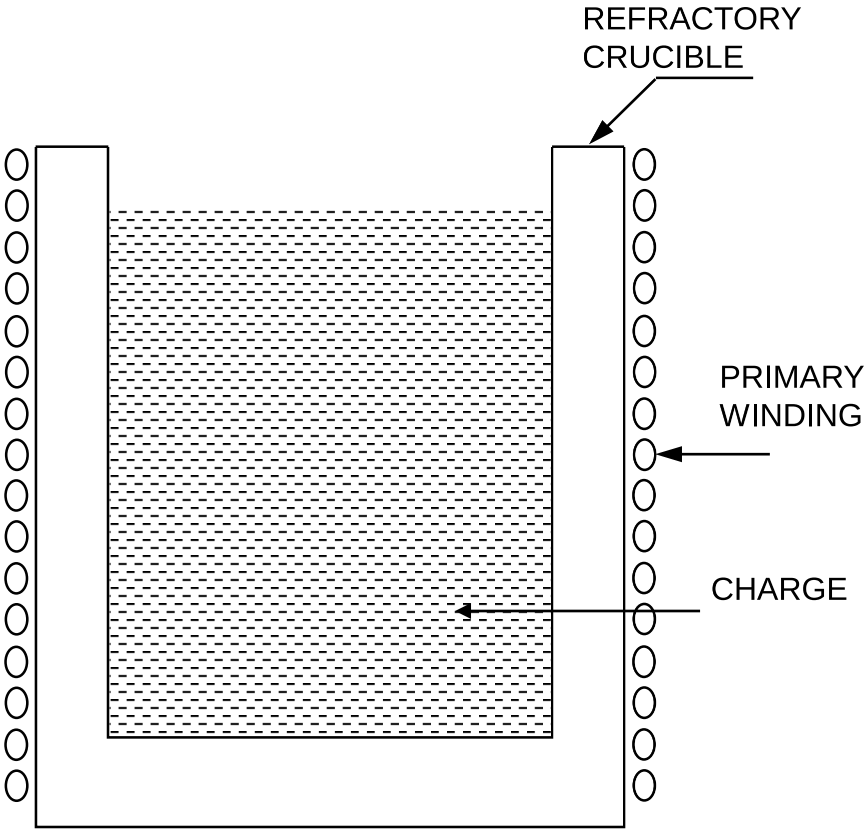
- The furnace consists of a refractory or ceramic crucible cylindrical in shape enclosed with in a coil which forms the primary of a transformer
- The furnace also may have a conducting or non-conducting container



Coreless Induction Heating

- When high frequency of 500 of 1000 Hz supply is given to primary windings

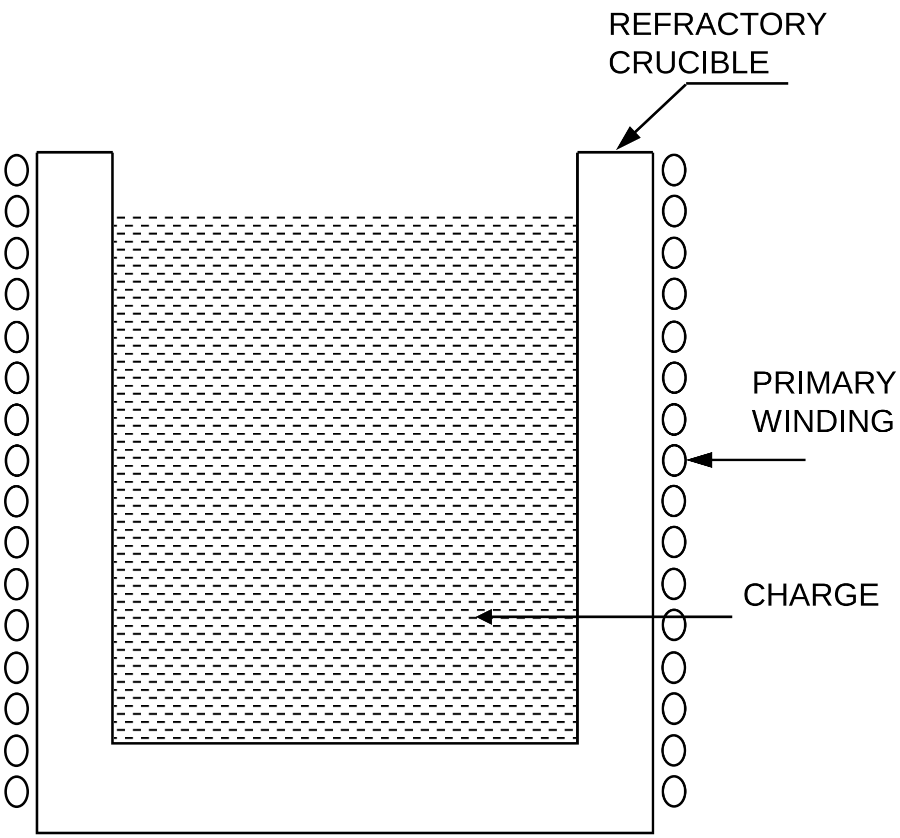
- The eddy currents are set up in charge or container by transformer action



Coreless Induction Heating

- There currents heat the charge to melting point and they also set up the electromagnetic force which produce a stirring action to the charge

- The furnace becomes relatively light in weight and can be easily tilted for pouring the metal



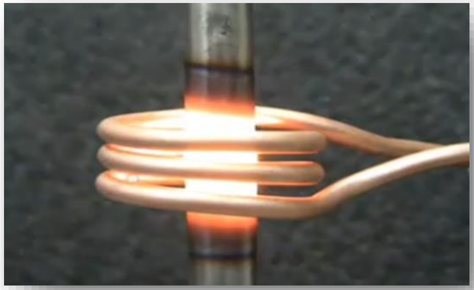
Coreless Induction Furnace

Advantages

- High speed of heating
- Well suited for intermittent operation
- High quality of product
- Low operating cost

Application

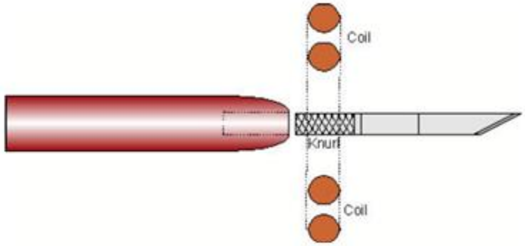
Industrial application



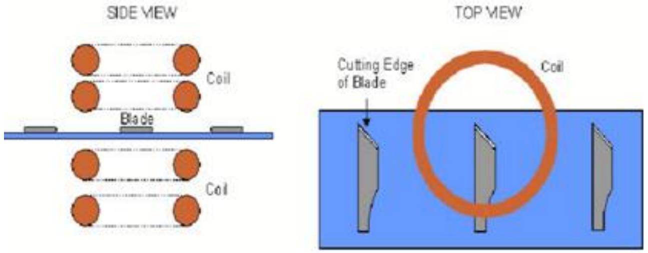
Housing applications

Medical application

(precision induction heating)

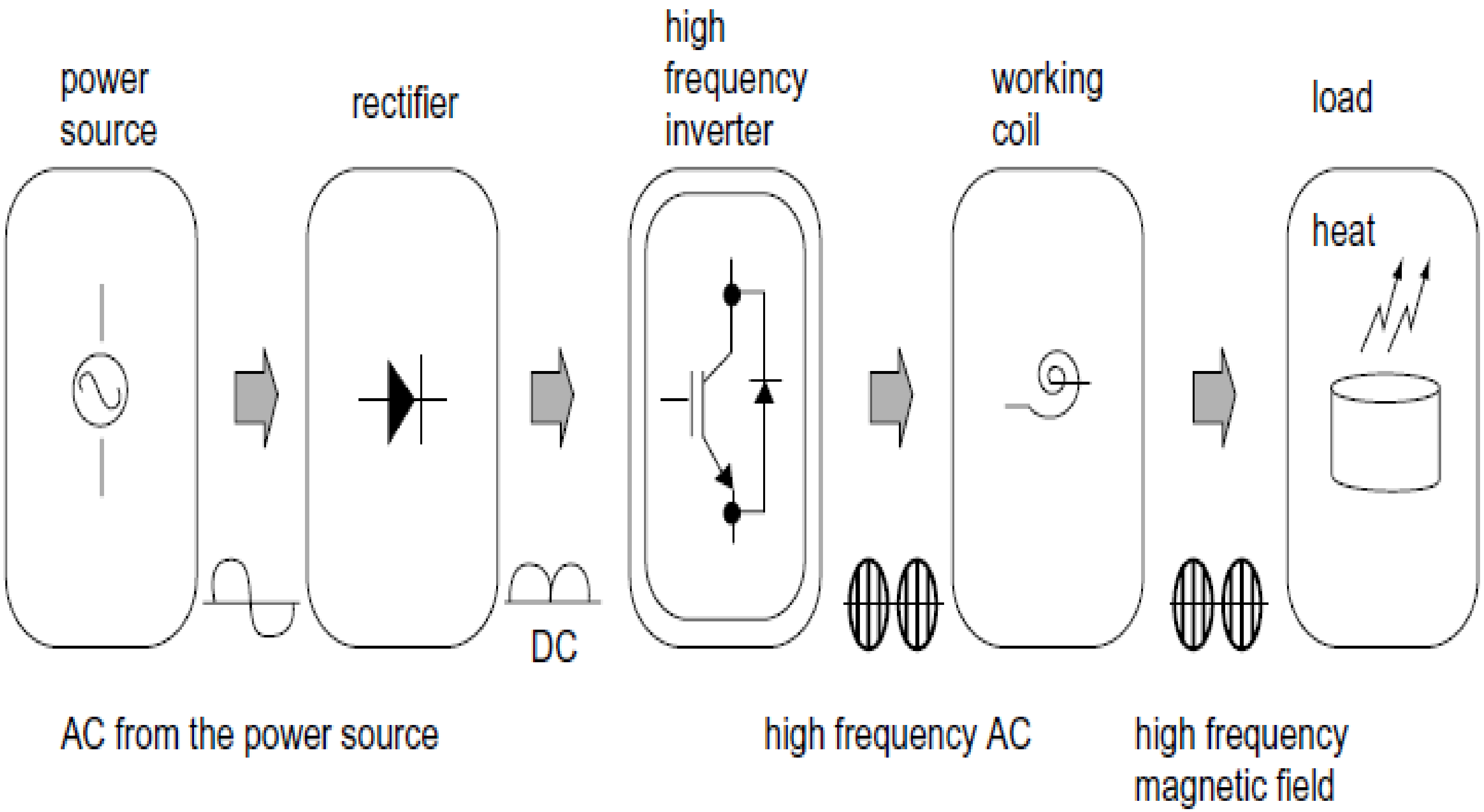


Bonding a plastic handle to a surgical knife



Hardening surgical blades

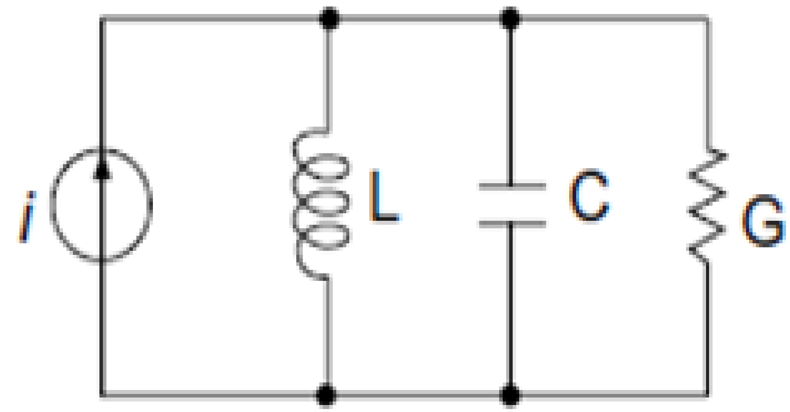
Design criteria



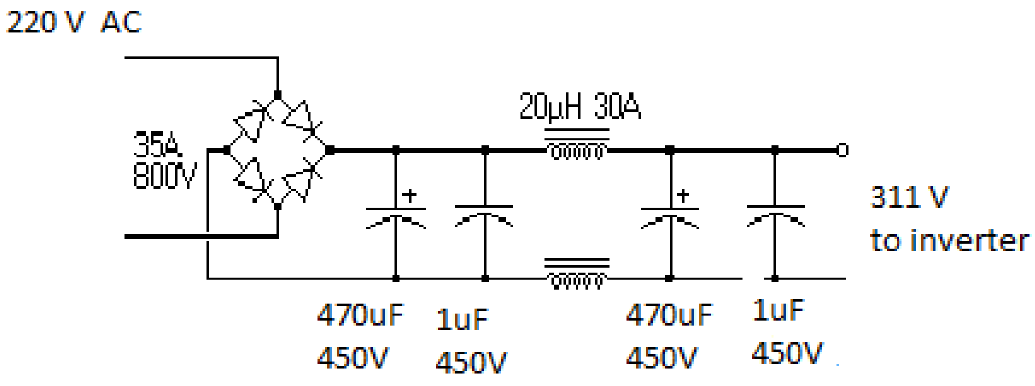
Induction Heating- Design aspects

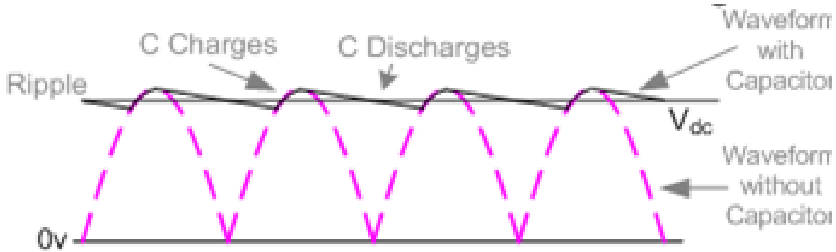
Parallel resonance

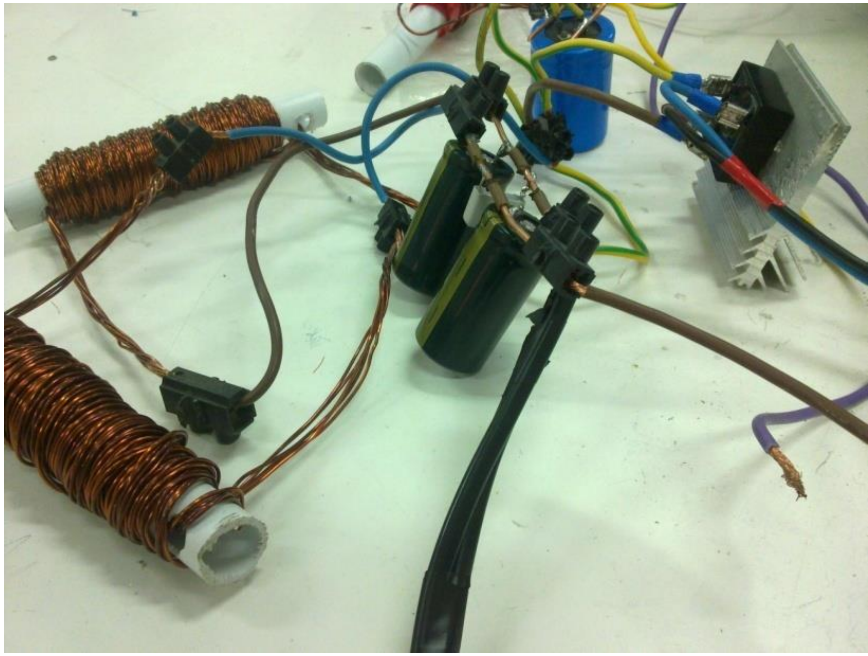
Tank circuit



High frequency power supply Design

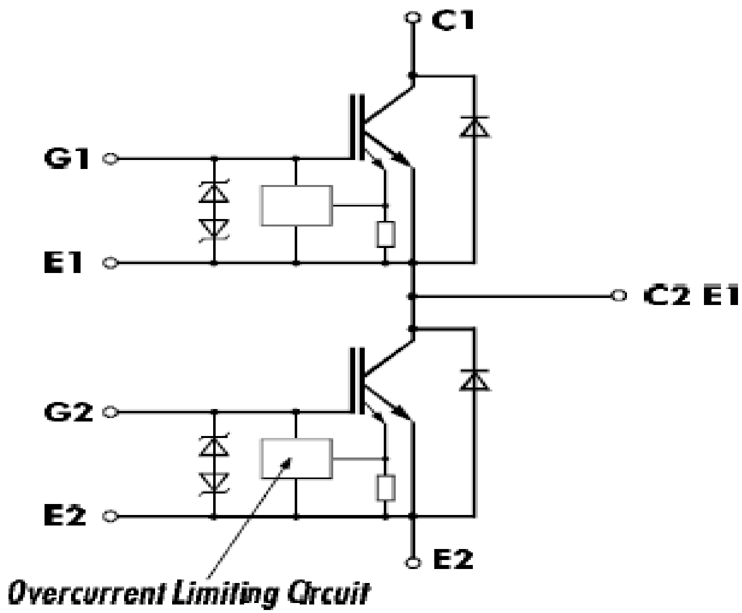


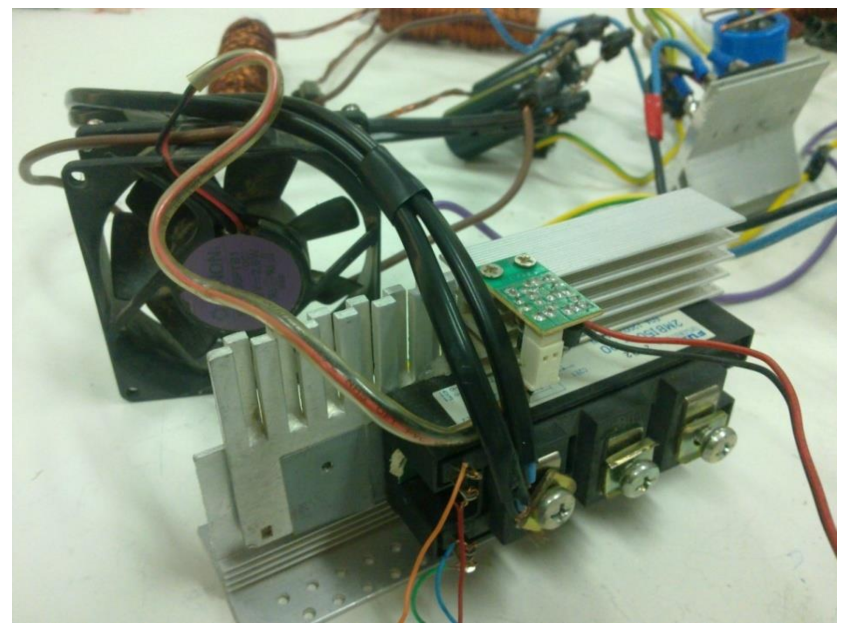




Practical design
High frequency power supply

- DC - source ⟶ High frequency AC source



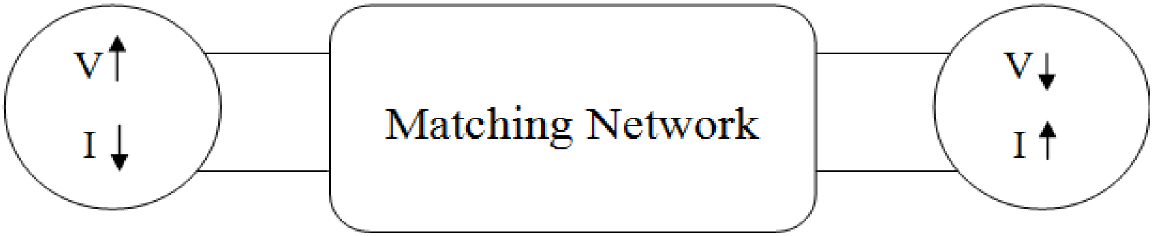


2MBI 50N-120 FUJI IGBT Module

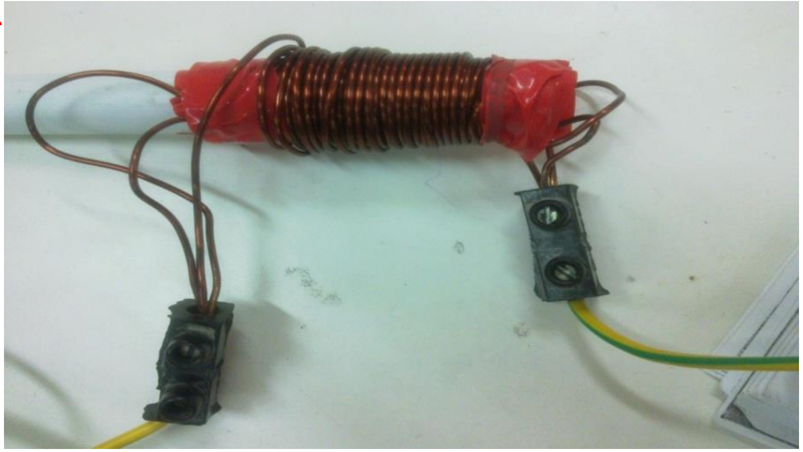
Matching Coil

Practical design

✓Fe



✓Matching circuit such as an L-match network



Practical design

- ***Induction Heating Work coil.***

- L=3.2 uH
- N=4.5 turns
- Inner diameter =7cm

- ***Induction Heating Capacitor.***

- ceramic capacitor
- 0.1 uF,450 V

To produce 3uF, 450 V.

Induction Cooking

- ✓ In induction cooking, an induction coil in the cook-top heats the iron base of cookware by magnetic induction.
- ✓ Copper-bottomed pans, aluminum pans and other non-ferrous pans are generally unsuitable. The heat induced in the base is transferred to the food by conduction.
- ✓ The benefits of induction cookers include efficiency, safety (the induction cook-top is not heated itself) and speed. Both permanently installed and portable induction cookers are available.

Induction Heating- salient points

- Induction heating is also known as high frequency heating.
- Induction heating process makes use of currents induced by electro-magnetic action in the material to be heated
- It uses transformer principle
- Conversion of electromagnetic energy into heat energy takes place in the material itself.
- Heat transfer by high frequency heating is as much as 10,000 W/cm^2
- The high frequency heating can be applied mainly to two classes of materials firstly, conducting materials & secondary insulating materials.
- Heating of first type of materials is called induction heating and heating of Second type of materials is dielectric heating.

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.

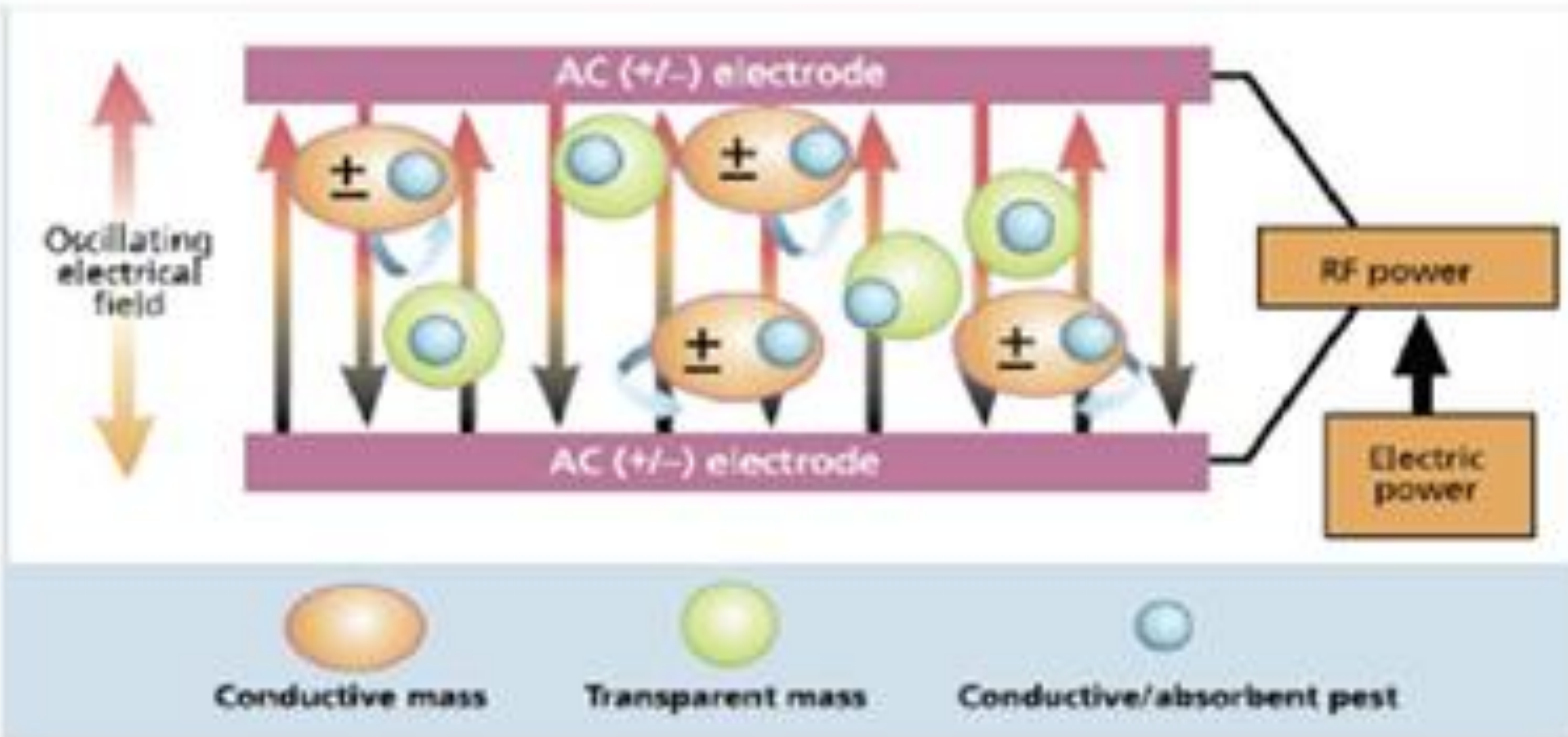
Comparison Between High Frequency And Power Frequency Furnaces

Contd..

7	Low capacity (few kgs. to 15 tons) furnaces are used	Large capacity (above 1 tone)
8	Initial cost is more	Less cost
9	High frequency (500 to 1000 Hz)	Only 50Hz.
10	Well suited for intermittent operation of different alloys.	Well suited for long production schedules of one alloy.
11	Care should be taken against stray field	Negligible.
12	Overall efficiency is low.	Overall efficient is more.

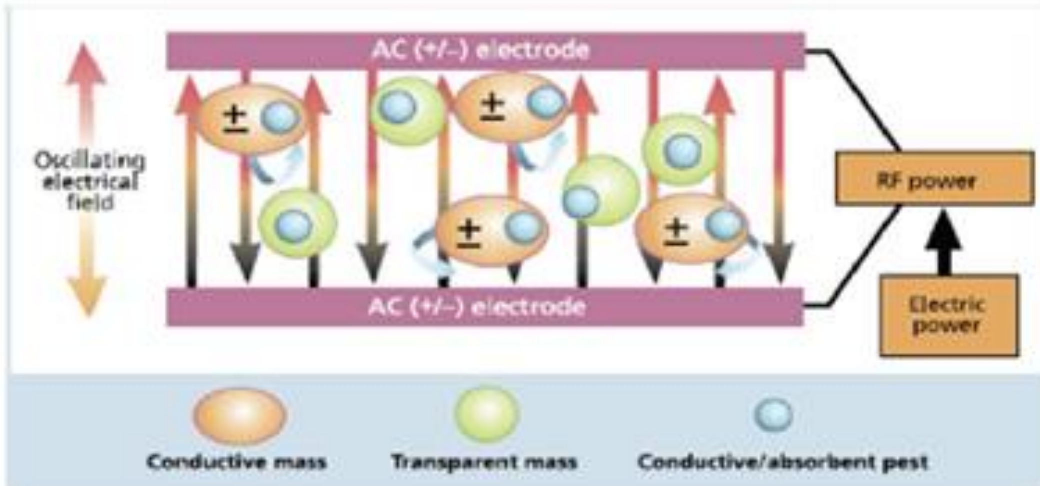
RF Heating

- Rapid heating, is a primary advantage of RF heating using electromagnetic waves (30-300MHz)
- Molecules within a product placed in an RF environment re-orient themselves (27 million times/s at 27 MHz) continuously in response to the applied field.
- It's a combination of dipole heating and electric resistance heating resulting from the movement of dissolved ions as present in the food.
- Initiates volumetric heating and uniform heating within the entire product due to frictional interaction between the molecules, thus selectively heats only the product and not the air or equipment surrounding it.
- It provides heating at high penetration depth that could be used to pasteurize or sterilize liquid products.



RF heating mechanism

- RF generator creates an alternating electric field between two electrodes.
- RF power is produced when electricity is applied to an RF generator whose signal is amplified and delivered to a parallel electrode system.



RF heating mechanism

- The material to be heated is placed in between the electrodes (RE Cavity) where the alternating energy causes polarization of the molecules, thus continuously re-orient themselves to face opposite poles.
- Energy absorption involves primary two mechanisms -dipolar relaxation and ionic conduction.

- The amount of heat generated in the product is determined by the frequency, the square of the applied voltage, dimensions of the product, dielectric constant and the dielectric loss factor of the material.

- In food materials, water is often the primary component responsible for dielectric heating. Due to their dipolar nature, water molecules try to follow the electric field associated with electromagnetic radiation as it oscillates at very high frequencies, thus producing heat.

- Secondary mechanism of heating is through the oscillatory migration of ions in the food that generates heat.

Note: Dielectric constant is the measure of the food material's ability to store electromagnetic energy; whereas dielectric loss factor is the material's ability to dissipate electromagnetic energy

Applications:

- Drying, baking & post-baking,
- Pasteurization of juices,
- Waste water treatment in diary industries,
- Disinfection in agricultural produce especially walnut, red and black pepper, poultry, fish industries, etc..

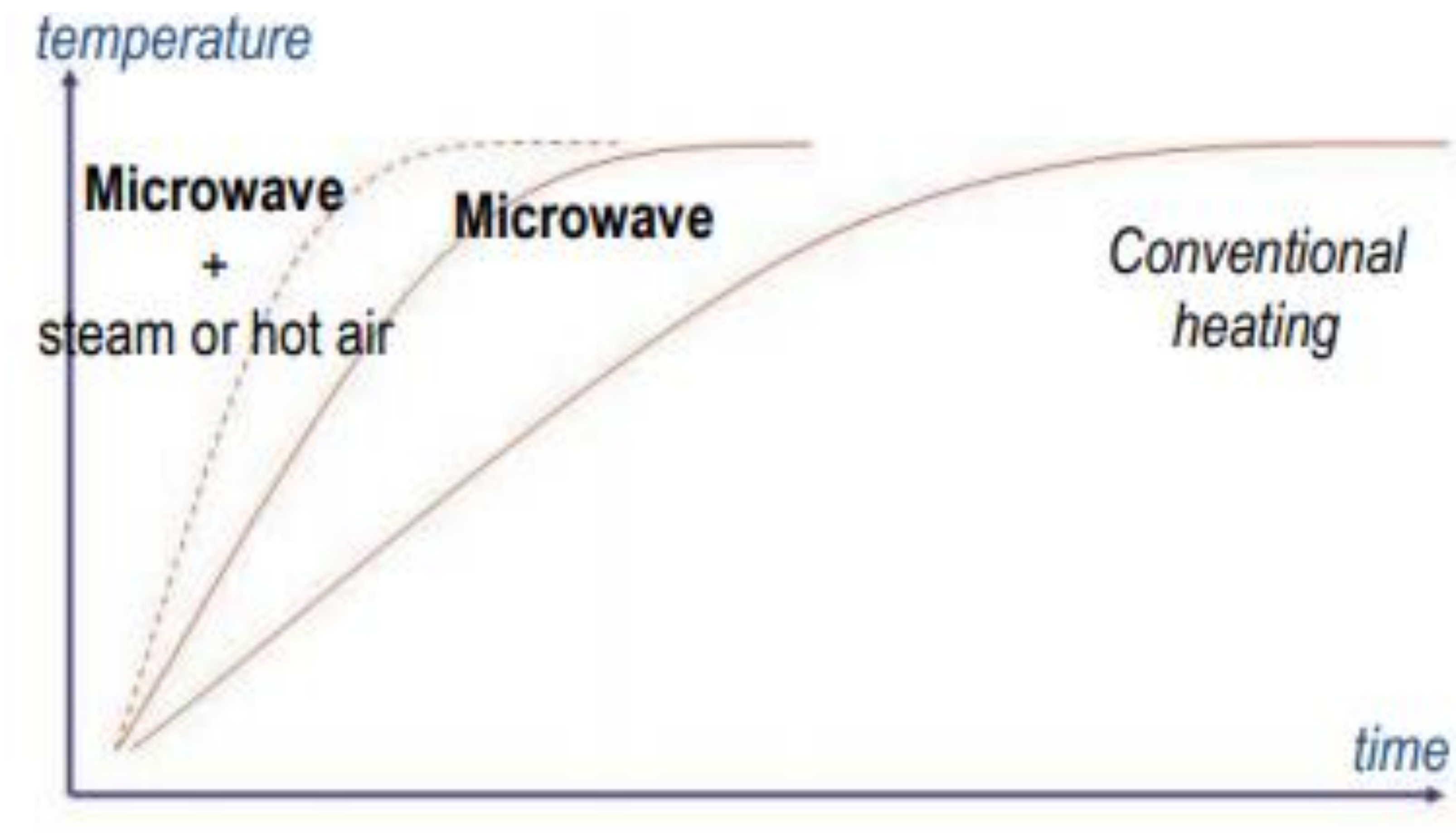
MICROWAVE HEATING

Microwave heating is a process within a family of induction, radio frequency, direct resistance or infra-red heating, all of which utilise specific parts of the electromagnetic spectrum.

- *Microwave heating takes place in* ***dielectric materials*** *such as foods due to the polarization effect of electromagnetic radiation at frequencies between 300 MHz and 300 GHz.*
- *The major advantages of using microwaves for industrial processing are rapid heat transfer, volumetric and selective heating, compactness of equipment, speed of switching on and off and pollution-free environment as there are no products of combustion.*

- *The high frequency regime provides primarily two physical mechanisms for energy transfer to a non-metallic material.*
- *At the lower microwave frequencies, conductive currents flowing within the material due to the movement of ionic constituents, such as salts for example, can transfer energy from the microwave field to the material.*
- *At the higher microwave frequencies , around 3000 MHz, the energy absorption is primarily due to the existence of permanent dipole molecules which tend to re-orientate under the influence of a microwave electric field.*
- *The re-orientation loss originates from the inability of the polarisation to follow extremely rapid reversals of the electric field. Therefore, the resulting polarisation phasor lags the applied electric field. This ensures that the resulting current density has a component in phase with the field, and therefore power is dissipated in the dielectric material.*

MICROWAVE HEATING



Basic equations in microwave heating

- The basic equations are the total current density established in the dielectric material and the modified wave equation.

- The total current density includes the contributions of conductive and displacement current densities and is given by the **curl of the magnetic field phasor**, **H**:

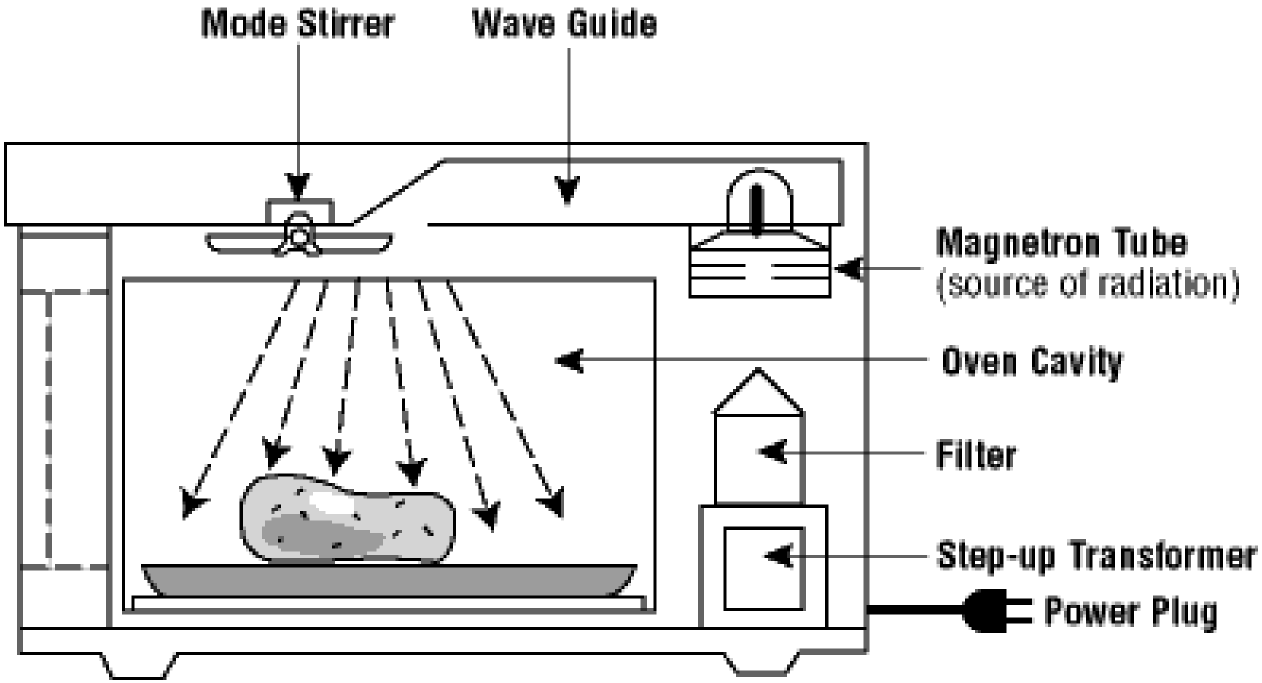
$$\nabla \times \mathbf{H} = \sigma\mathbf{E} + \partial\mathbf{D}/\partial t.$$

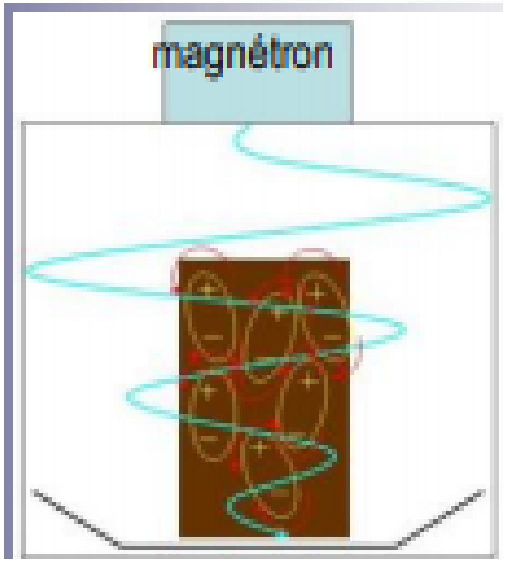
where, the 1st term on the right hand side is the conductive contribution due to ionic constituents and the 2nd term is due to the displacement current density **D** = ε**E**, where **E** being the applied electric field phasor, **ε** is the absolute permittivity and **σ** is the effective dielectric conductivity.

MICROWAVE HEATING

- ***In Microwave heating, an <u>electromagnetic wave is launched from a small dimension emitter and guided through space to the target</u>.***
- ***Microwave ovens make use of electromagnetic waves with electric fields of much higher frequency and shorter wavelength than <u>RF heaters</u>.***
- ***The way in which a material will be heated by microwaves depends on its shape, size, dielectric constant and the nature of the microwave equipment used.***

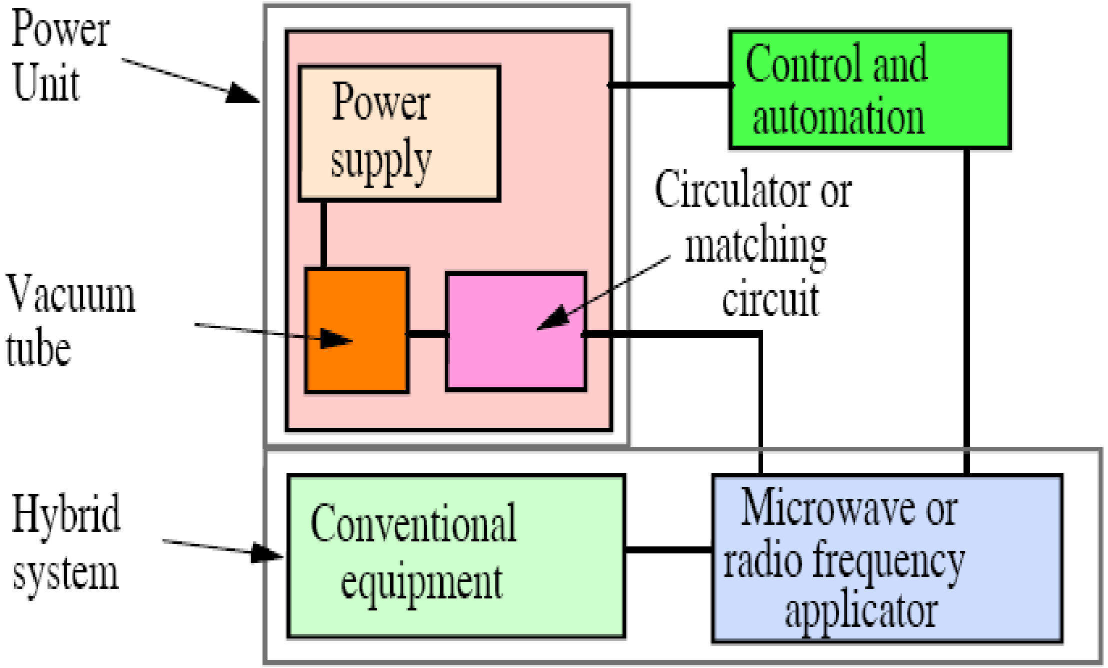
SCHEME OF MICROWAVE OVEN





Magnetron is designed to generate microwaves, a fairly short radio waves —you can't hear and can't see that energy (eyes aren't sensitive to short-wavelength, microwave radiation).

INDUSTRIAL SYSTEMS



- ***Basically there are three major components:***
- ***The first component is the power unit where microwaves are generated at the required frequency band.***
- ***The second component forms the applicator, where the material is subjected to intense microwave fields, and to which any additional ancillary process equipment such as pumps for operation under moderate vacuum conditions, steam or hot air injection, must be connected.***
- ***The third major component is the control circuitry to optimise and regulate the overall performance of the microwave heater. Magnetron tubes are used primarily to generate the microwave power.***

MICROWAVE HEATING APPLICATIONS

- ***Food tempering:*** *Meat, fish, fruit, butter and other foodstuffs can be tempered for cold store temperature to around -3°C for ease of further processing such as grinding the meat in the production of burgers or blending and portioning butter packs.*

- **Food processing** (Heating & cooking, ***Pasteurisation & sterilisation***), vitrification of nuclear wastes, treatment of highly toxic substances, waster recover of plastics, pyrolysis, heating of resins, polymerisation, heating of oil sands and the processing of minerals, Vacuum drying.

- **Sintering of a wide range** of ceramics and composites, joining and calcining of superconductors or electro-ceramics.

- ***Pre-heating for rubber vulcanization***

Pre-heating for rubber vulcanization

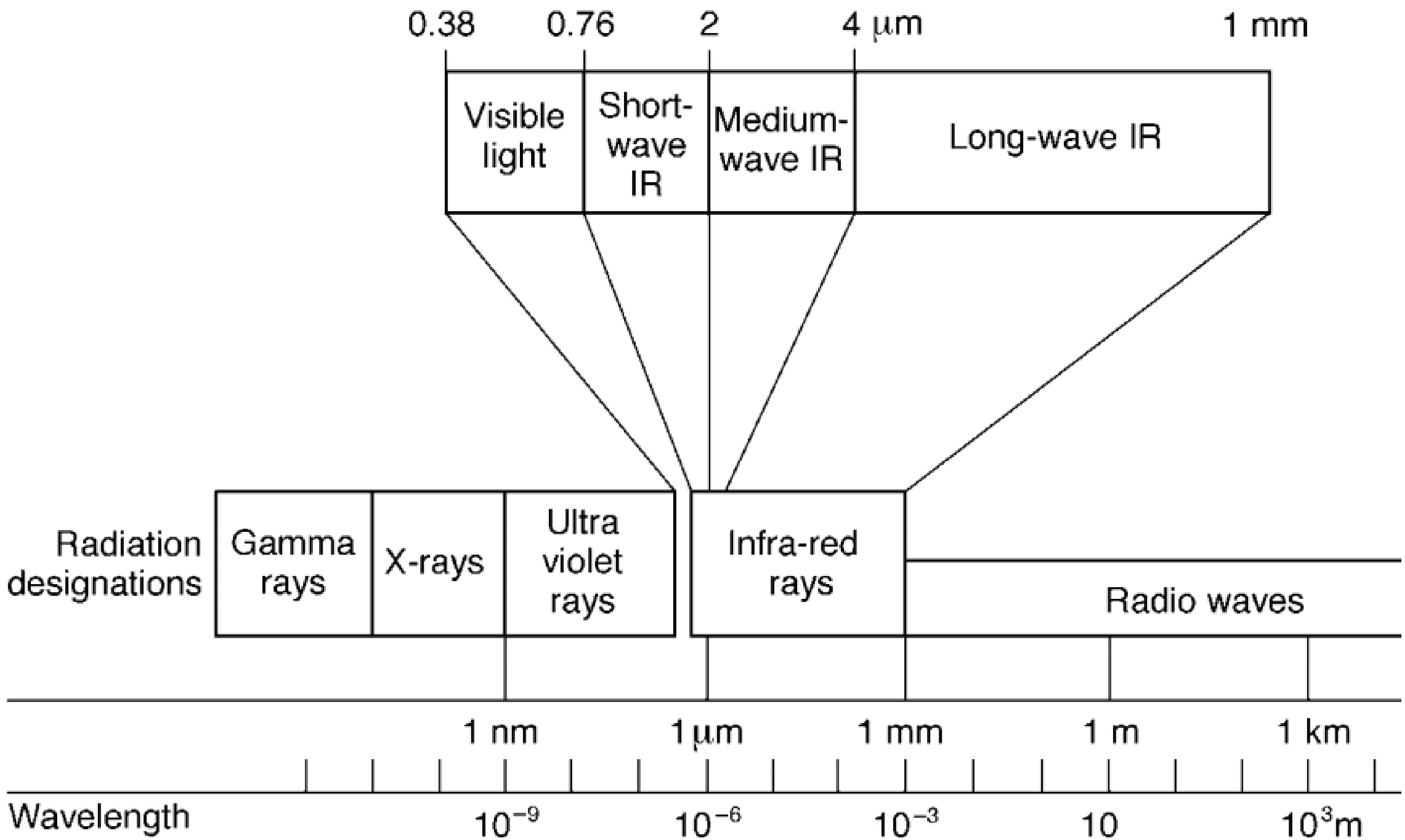
- *The temperature of rubber extrusions can rapidly and uniformly be brought up using microwave energy to the required level, for cross-linking of the bonds to commence.*

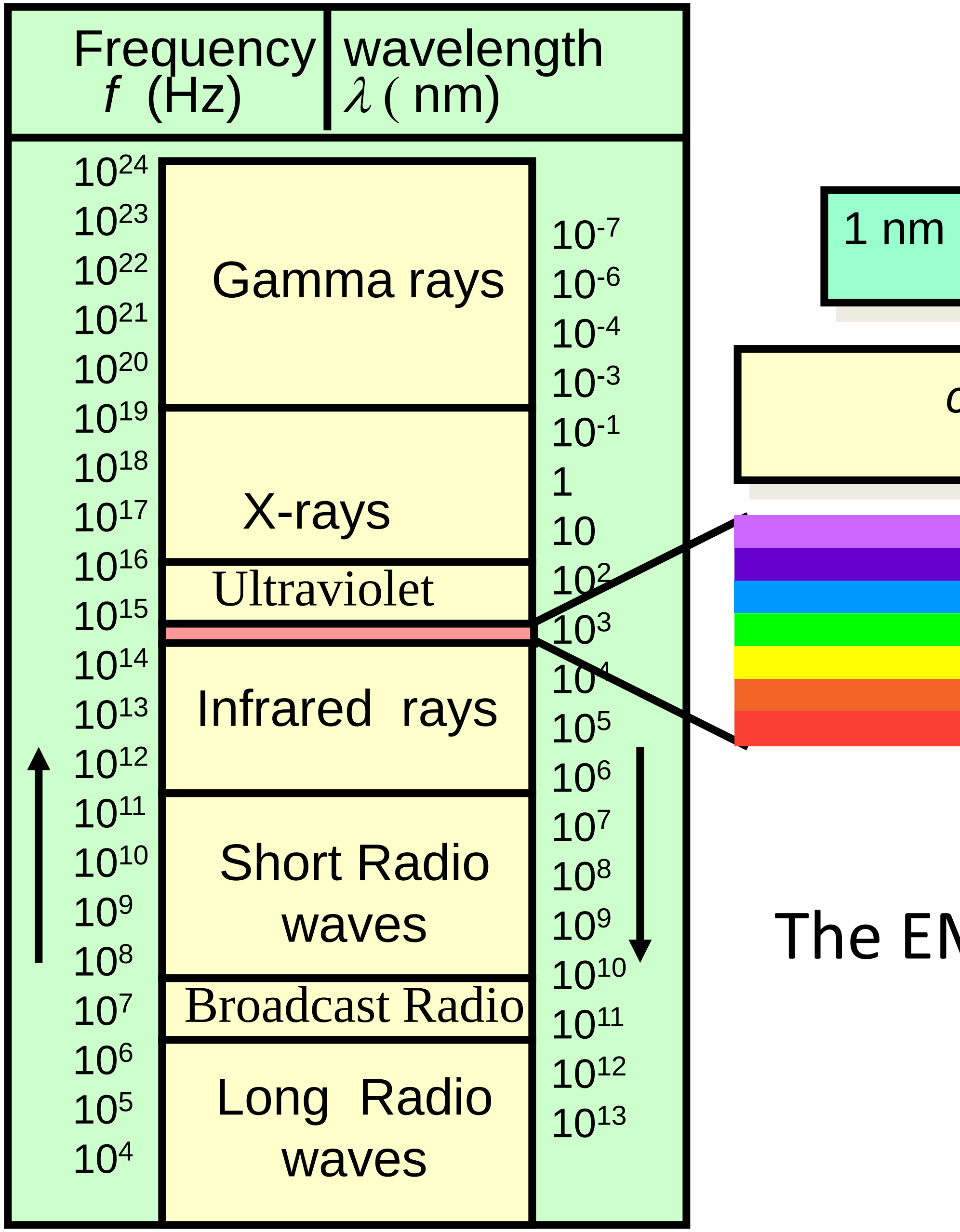
END

Infrared Heating

Infrared Heating

- ……….ideal source of energy for heating purposes





1 nm = 1 x 10^{-9} m

$c = f\lambda$ $\quad c = 3 \times 10^8$ m/s

The EM Spectrum

- Infrared waves lie between microwaves and visible waves.

- Wavelength: 7.5×10^{-7} to 0.001 Meters

  Shorter Wavelengths
  - "Near infrared" light is not hot at all.
  - Waves are about the size of microscopic cells.

  Longer Wavelengths
  - Waves are able pass through clouds of dust, water vapor.
  - Waves are thermal.
  - Waves are about the size of a pin head.

- Frequency: 8×10^{10} to 4×10^{14} Hertz

- The short waves appear when temperatures are above 1000ºC; the long waves appear below 400ºC and medium waves between these temperatures.

Infrared radiation (IR)

- IR is electromagnetic radiation with relatively long wavelengths compared to visible light.

- IR emitted from all objects that are at a temperature above absolute zero.

temperature of the source determines the wavelength of infrared radiation. Higher temperatures produce shorter wavelengths and greater depth of penetration.

- An object with a higher temperature will transmit heat by electromagnetic radiation to any object at a lower temperature.

- **The rate of heat transfer will be proportional to the differences between each temperature raised to the power of four.**

- Also, the emitting efficiency of the heater and the absorption efficiency of the material/food being heated will influence the heating rate.

- As the temperature of the heat emitter is increased, the heating rate goes up very rapidly.

IR Characteristics :

- High heat transfer capacity,
- Heat penetration directly into the product,
- Fast regulation response and
- Good possibilities for fast process control, and
- No heating of surrounding air.

IR Characteristics

- **The rate of heat transfer depends on**

  (i) Surface temperature of the heating and receiving materials

  (ii) Surface properties of the two materials &

  (iii) Shape of the emitting and receiving bodies

Infrared heater or **heat lamp** is a body with a higher temperature which transfers energy to a body with a lower temperature through electromagnetic radiation.

Depending on the temperature of the emitting body, the wavelength of the peak of the infrared radiation ranges from 780 nm to 1 mm. No contact or medium between the two bodies is needed for the energy transfer.

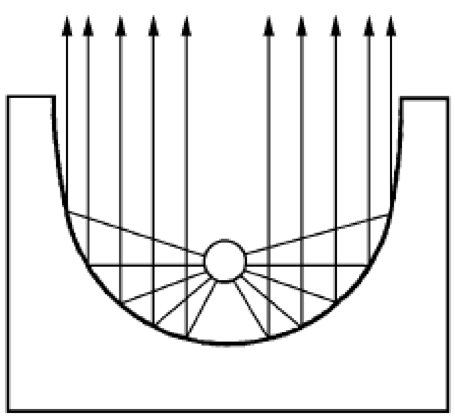
Infrared heaters can be operated in vacuum or atmosphere.

Equipment

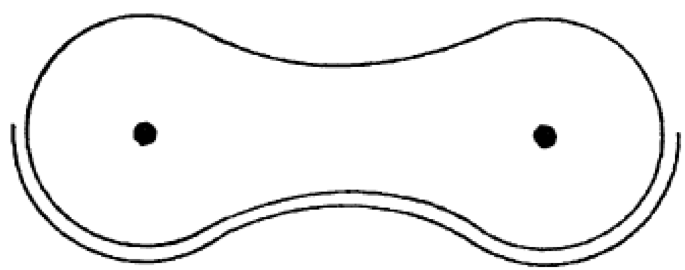
- **Radiator, the main** component – Need of right type of infrared radiators.

- **1. Gas-heated radiators (long waves)**
- **2. Electrically heated radiators**
  - – tubular/flat metallic heaters (long waves)
  - – ceramic heaters (long waves)
  - – quartz tube heaters (medium and short wave)
  - – halogen heaters (ultra short waves)

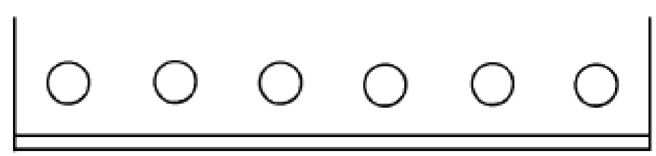
- The reflection at short wavelength is high, approximately 50% and at longer wavelengths is less than 10%. It is therefore significant to choose the right type of infrared radiators.



(a) Individual reflector



(b) Individual gilt twin quartz tube



(c) flat metallic ceramic cassette reflector

Properties of IR reflection

The amount of heat emitted from a perfect radiator (termed black body) is calculated using the Stefan-Boltzmann equation

$$Q = \sigma A T^4$$

where Q ($\mathrm{Js^{-1}}$) is the rate of heat emission, σ ($= 5.7 \times 10^{-8}\,\mathrm{J\,s^{-1}\,m^{-2}\,K^{-4}}$) the Stefan-Boltzmann constant, A ($\mathrm{m^2}$) the surface area and T ($\mathrm{K} = {}^{\circ}\mathrm{C} + 273$) the absolute temperature. This equation is also used for a perfect absorber

However, radiant heaters are not perfect radiators and foods are not perfect absorbers.

To take account of this, the concept of grey bodies is used,

and the equation is modified to

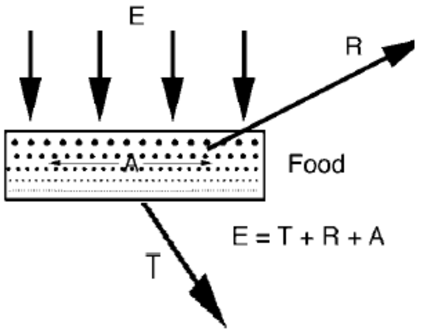
$$Q = \varepsilon \sigma A T^4$$

Here ε is the emissivity of the grey body expressed as a number from 0 to 1. Emissivity varies with the temperature of the grey body and the wavelength of the radiation emitted.

Physics of IR reflection

When infrared waves hit a material they are reflected r, transmitted t or absorbed α (see Fig.).

The amount of radiation absorbed by a grey body is termed the absorptivity α and is numerically equal to the emissivity. Radiation, which is not absorbed, is reflected and this is expressed as the reflectivity $1-\alpha$. The amount of absorbed energy, and hence the degree of heating, varies from zero to complete absorption. This is determined by the components of food, which absorb radiation to different extents



The absorbed waves are transformed to heat and the <u>temperature of the material increases</u>.

When the waves penetrate the material, the **vibrations and rotation of the molecules are changed**. The two fundamental vibrations that occur are stretching and bending. Stretching means a decrease or an increase of the distance between atoms and bending means a movement of the atoms. **When the infrared light hits a molecule, energy is absorbed and the vibration changes. When the state of the molecule returns to the absorbed, energy will be transformed to heat.**

The net rate of heat transfer equals the rate of absorption minus the rate of emission:

$$Q = \varepsilon\sigma A(T_1^4 - T_2^4)$$

where T_1 (K) is the temperature of emitter and T_2 (K) the temperature of absorber.

Optical properties/IR reflection …….contd.

- For materials with rough surfaces, both regular and body reflection will become diffuse.
- The penetration properties are important for optimising the system.
- Penetration depth is defined as 37% of the unabsorbed radiation energy. For short waves, the penetration ability is ten times higher than for long waves.

Product	Radiation source $\lambda_{max}(\mu m)$	Penetration depth Wavelength range (μm) $\lambda < 1.25$	$1.25 < \lambda < 1.51$	$\lambda > 1.51$
Potato	1.12	4.76	0.48	0.33
Potato	1.24	4.17	0.47	0.31
Pork	1.12	2.38	0.28	
Bread	1.12	6.25	1.52	

Infrared Heating in Industry:

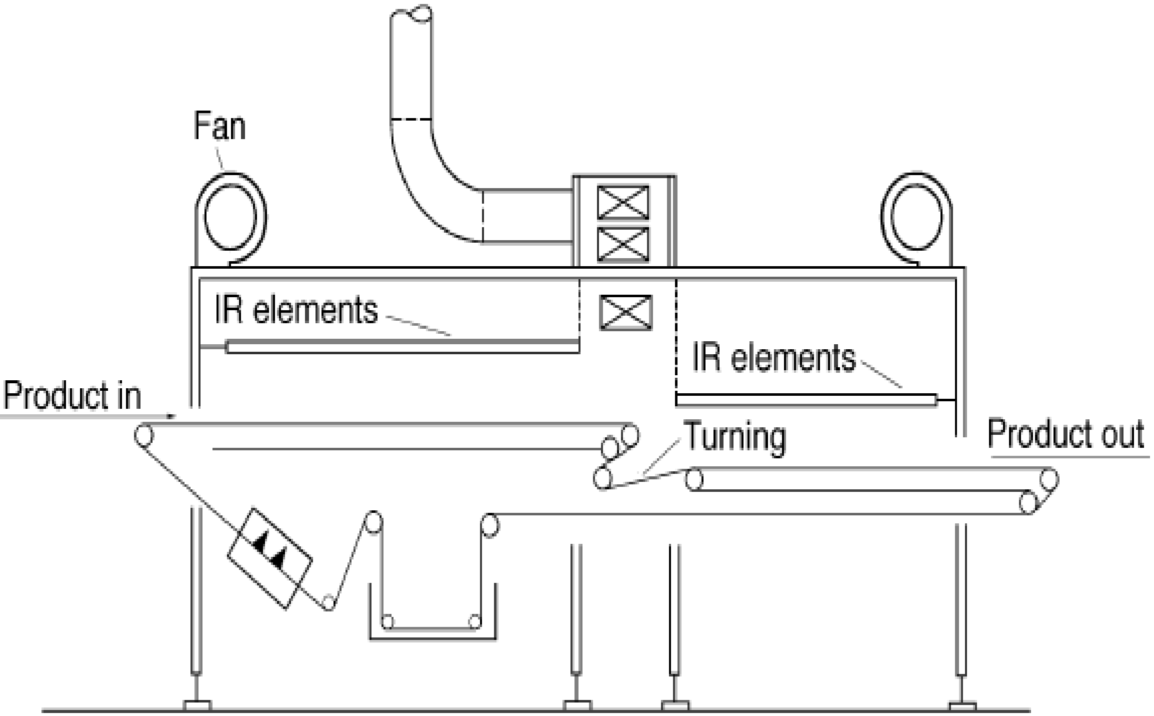
- In industrial heating applications centres on short wave IR (wavelengths around 1 μm) and intermediate IR (around 10 μm), and enables to start up and reach working temperatures in seconds and provides excellent process control.

- In some food materials, moreover, short wave IR demonstrates a penetration depth of up to 5mm.

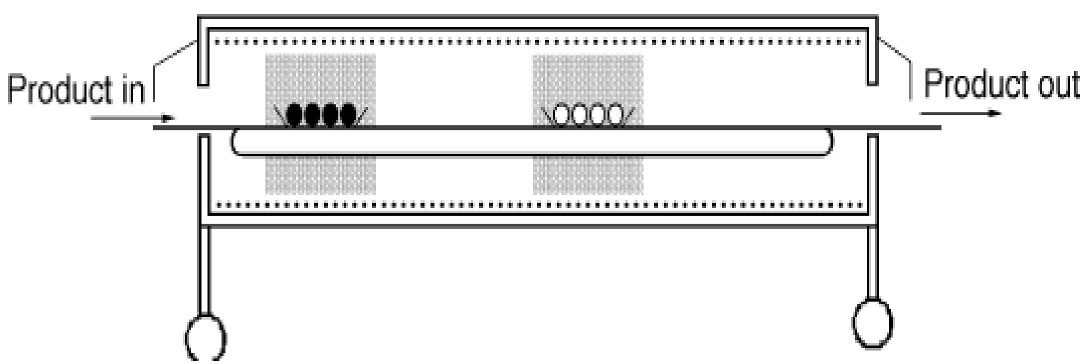
- For paper drying IR has superseded microwaves because it offers superior process control and economy.

- IR technology has its great potential in the food field. The main commercial applications of IR heating are drying low moisture foods (examples are drying of breadcrumbs, cocoa, flours, grains, malt, pasta products and tea).

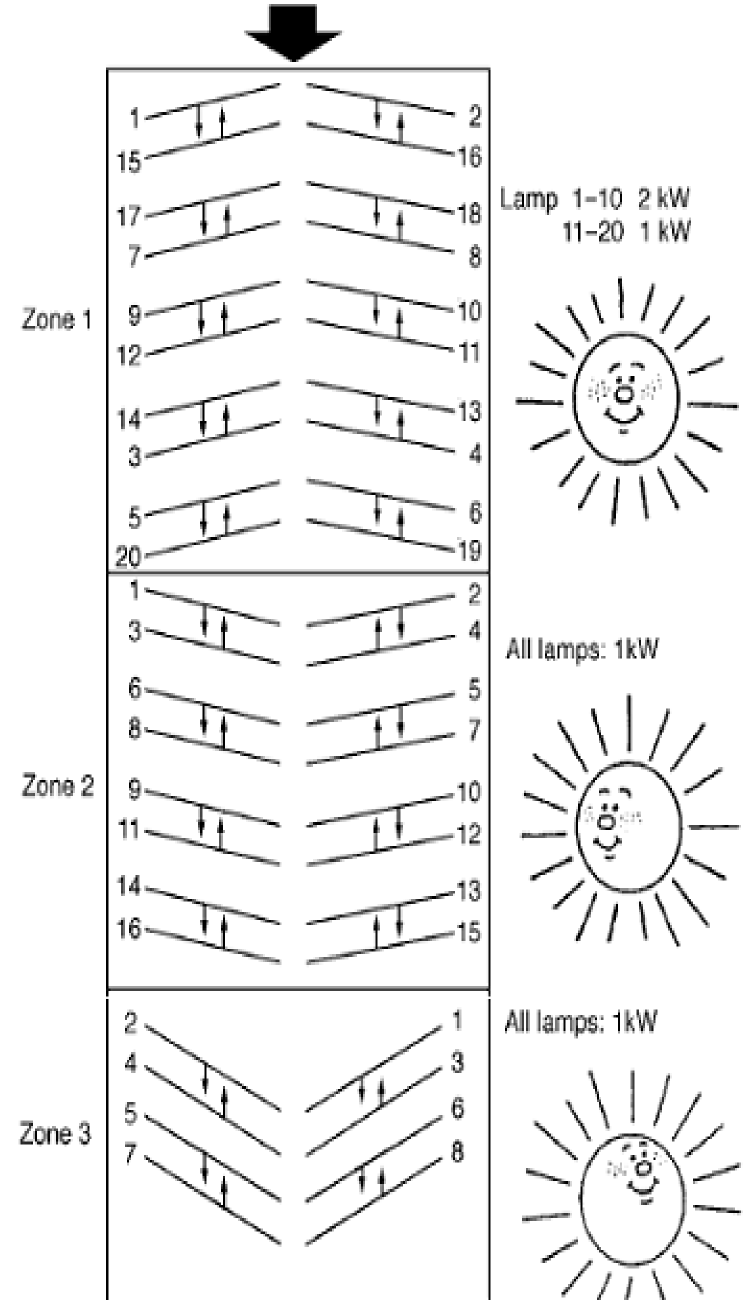
- IR ovens or equipment of various sizes and constructions have been developed and tested in many countries.



Continuous process infrared oven.



Infrared oven in which heating is from above and below the product: this oven utilises individual pans for the product.



Infrared oven.

Benefits

Benefits	manufacturer	retailer & caterer	consumer
Rapid heating method (normally faster than convective or conduction heating, slower than microwave and radio frequency heating).	x		
It uses a substantially less amount of energy.	x		
Infrared heaters are cleaner and more environmentally friendly, less costly to operate, and provide more effective heating than traditional heaters	x	x	x
Infrared heaters emit a safe and gentle heat. Therefore not the risk of burning.	x	x	x
Since IR heating does not penetrate the surface very deeply and generally only heats the outer surface, it is applicable for drying coated products.	x		

Shortcomings
To date, it has been confined to solid and semi-solid foods.

Benefits…..contd.

- Glass allows visible light to pass through but traps infrared light instead of transmitting it.
- Infrared waves are not dangerous to humans unless concentrated in one spot.
- Humans, animals, the Earth, the Sun, stars and galaxies and even ice radiate infrared light.
- The higher the temperature, the more rays. If the temperature is very high there will be rays of visible and infrared light.
- The biggest source of radiation heat is the sun. Its infrared radiation heats the earth's atmosphere.

Applications:

- drying of vegetables, fish
- drying of pasta, rice
- heating of flour
- frying of meat
- roasting of cereals
- roasting of coffee
- roasting of cocoa
- baking of pizza, biscuits and bread.
- used for thawing, surface pasteurisation of bread and pasteurisation of packaging materials.

Applications ....contd.

- Used for drying of dye and lacquer for cars, drying of glue for wallpaper, drying of paper in a paper machine, drying of dye to plastic details, shrinkage of plastics, activation of glue in the plastic industry.

- Temperature of a distant object can be determined by analysis of the infrared radiation from the object.

- **Ref.: Infrared heating -C. Skjojldebrand, ABB Automation Systems (formerly Swedish Institute of Food Research (SIK)), Tumba**

Applications

Medical uses of infrared radiation range from the simple heat lamp to the technique of thermal imaging, or thermography.

In medicine, the RF heating of body tissues, called diathermay, is used for muscle therapy. Heating to higher temperatures, called hypethermia therapy, is used to kill cancer and tumor tissue.

In agriculture, RF dielectric heating has been widely tested and is increasingly used as a way to kill pests in certain food crops after harvest,


Thank You!