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Classroom Slides Set-1

Utilization of Electrical Power

Electric Heating & Welding

Electric Heating: Syllabus

Utilization of Electrical Power

Electrical Heating

Electric heating and welding- advantages and types of electric heating- properties of resistance heating materials- design of heating elements- Resistance ovens- methods of temperature controls.

Induction heating- Principle- factors affecting induction heating- induction furnace- core type and core less type- high frequency eddy current heating- dielectric heating- equivalent circuit loss angle application of dielectric heating- Arc furnace- direct and indirect types.

Classroom Slides Set-1

- What is heating ??
- Advantages of Electrical heating
- Application of Electrical heating
- ❖ Modes of heat transfer
- ❖ **Classification of electrical heating**
  - **Resistance heating** → Direct resistance heating / Indirect resistance heating
  - **Arc heating** → Direct Arc heating / Indirect Arc heating
- ❖ Properties of a good heating element
- ❖ **Heating elements**
- Design of resistance heating element
- Temperature control of resistance furnaces/ovens
- Radiant or Infrared heating
- ❖ **Induction Heating**
- ❖ Type of Induction Furnace → Core type / Coreless type
- ❖ **Dielectric Heating**

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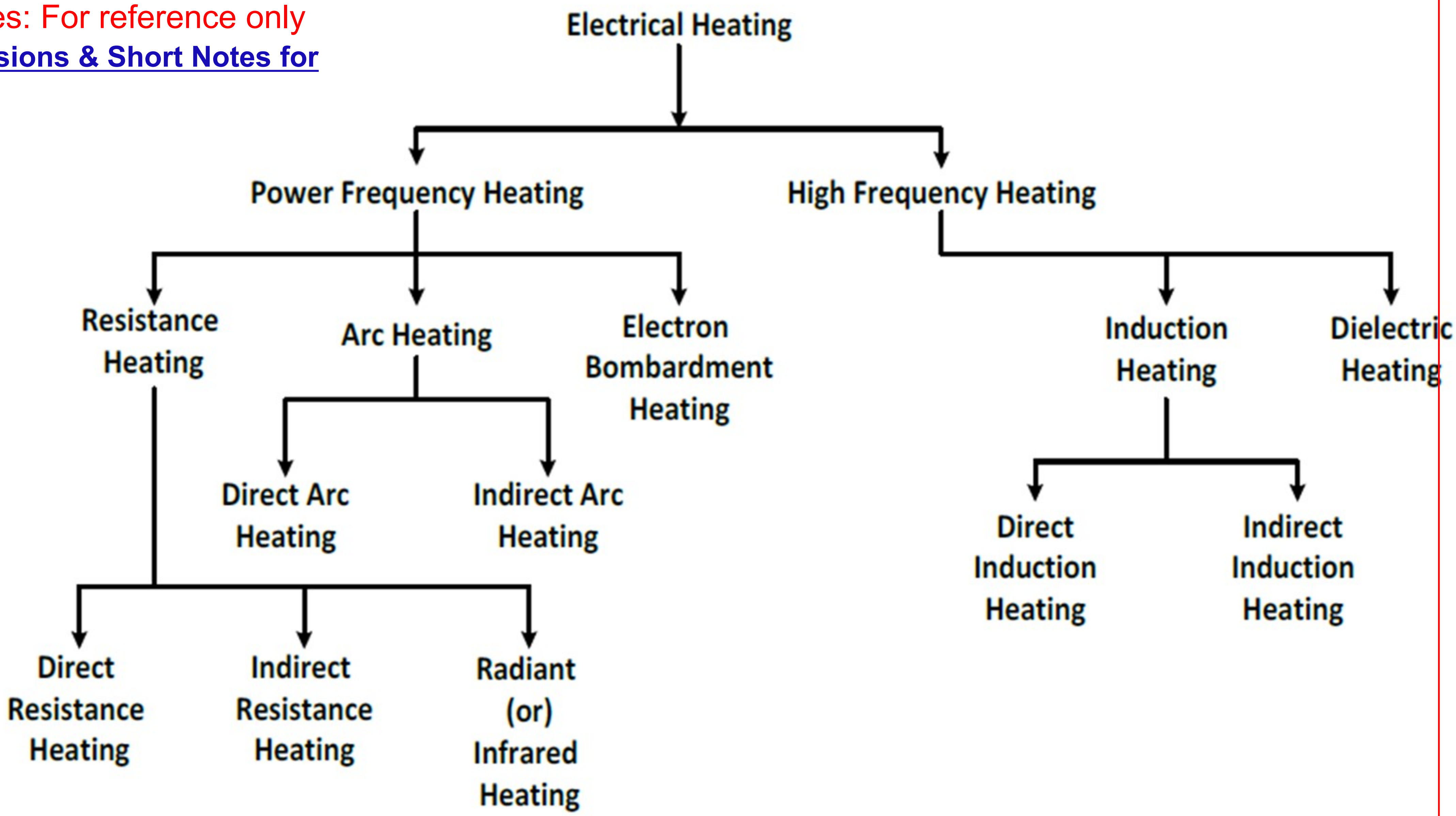


Electric Heating

Classroom Slides Set-1

What is Heating ??

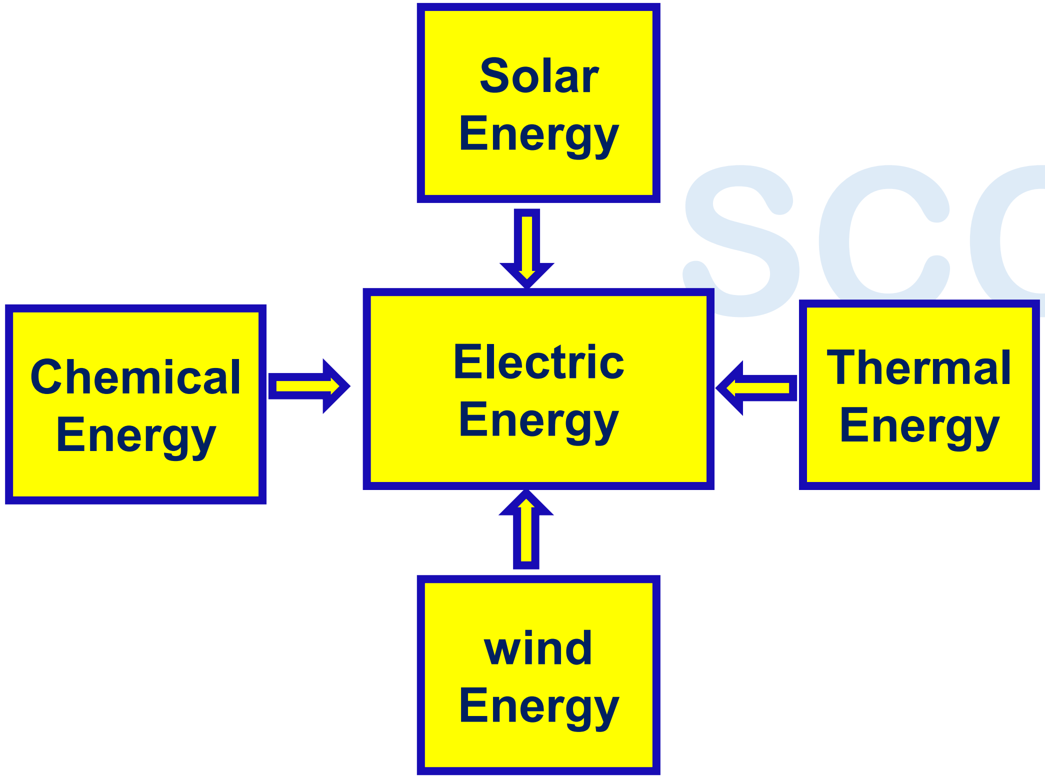
- Heating is normally produced by burning (Wood, Coal, Gas, Oil)
- Burning of any fossil fuel will cause pollution, ash, smoke

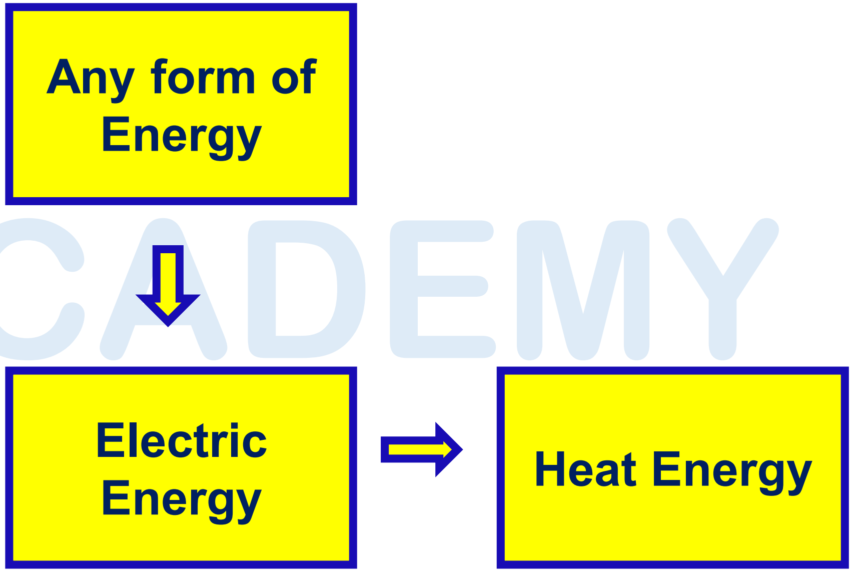



Electrical Heating

Classroom Slides Set-1

Heat is generated using electrical energy by converting the Electrical Energy into Heat Energy





Advantages of Electric Heating

1. Ease of control

Temperature can be controlled and regulated accurately

2. Uniform heating

The substance can be heated uniformly throughout whether it may be conducting or non conducting material

3. Special heating requirements

Special heating requirements such as uniform heating or heating one particular portion of a job without affecting the other parts or heating with no oxidation is met only by electric heating

4. High efficiency

In non electrical heating only 40-60% of heat is utilized but in electrical heating **75-100%**

Advantages of Electric Heating

5.High temperature

High temperature can be obtained by the electrical heating except the ability of the material to withstand the heat

6. Economical

Electrical heating equipment is cheaper, they do not require much skilled Persons, therefore maintenance cost is less

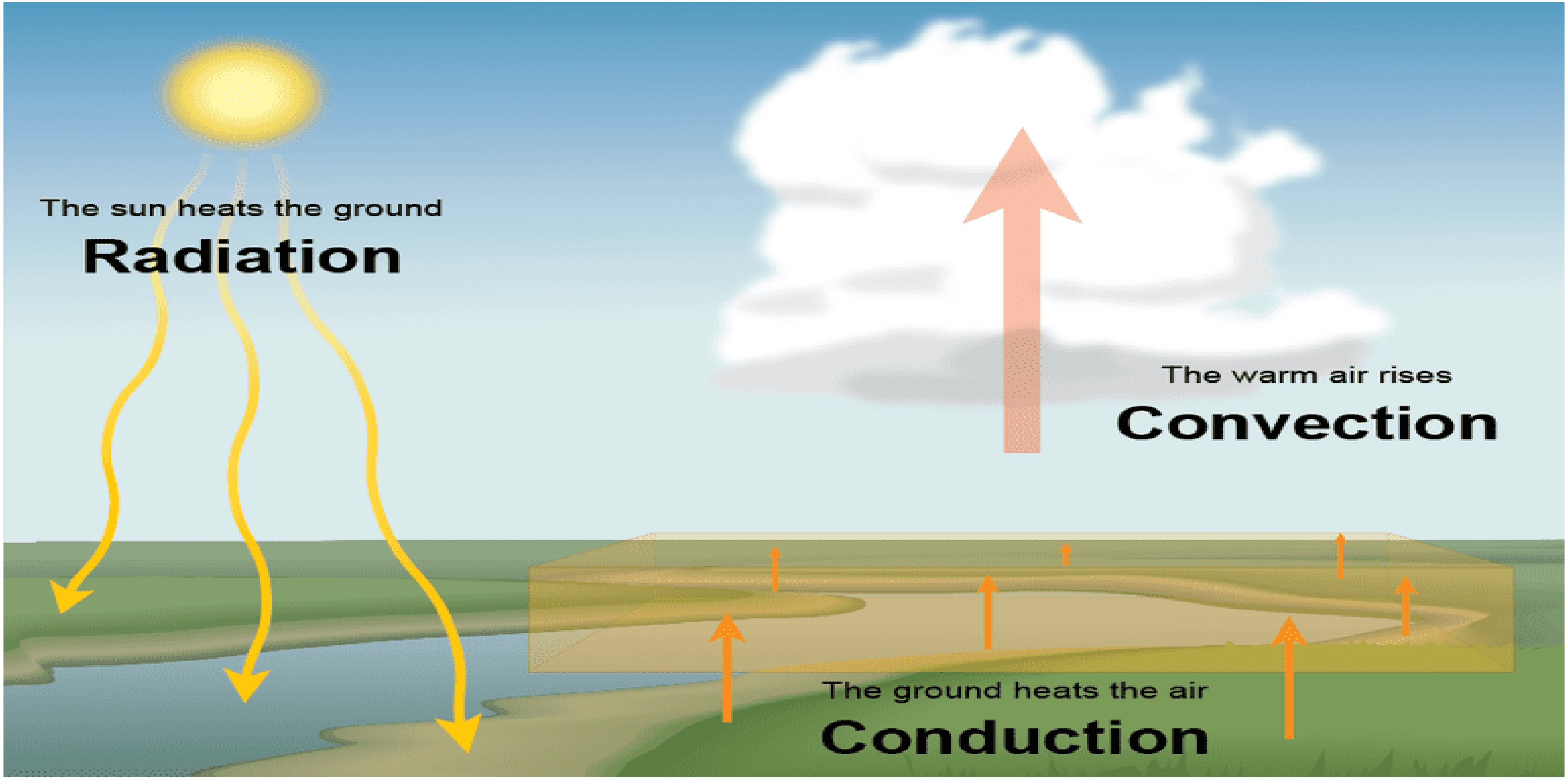
7. Pollution free & Clean

Dust and ash are completely eliminated in this process

8. Low maintenance cost & Safer operation

Application of Electrical Heating

Domestic	Industrial
Room heater	Annealing
Water heater	Tempering
Cooking	Soldering
Electric iron	Melting of metals



Energy is transferred between the Earth's surface and the atmosphere in a variety of ways, including radiation, conduction, and convection.

Modes of Heat Transfer

The transmission of heat energy from one body to another because of the temperature gradient take place by three methods

1. Conduction
2. Convection
3. Radiation

Conduction

Classroom Slides Set-1

- One molecule of substance gets heated and transfers the heat to the adjacent one and so on
- The heat transfer from one part of substance from another part without the Movement in the molecule
- The rate of conduction of heat along the substance is depends upon the temperature Gradient
- Conduction of heat transfer in gases and liquid is due to the collision and diffusion Of the molecules during their random motion
- Conductive heat transfer can be expressed with Fourier's Law

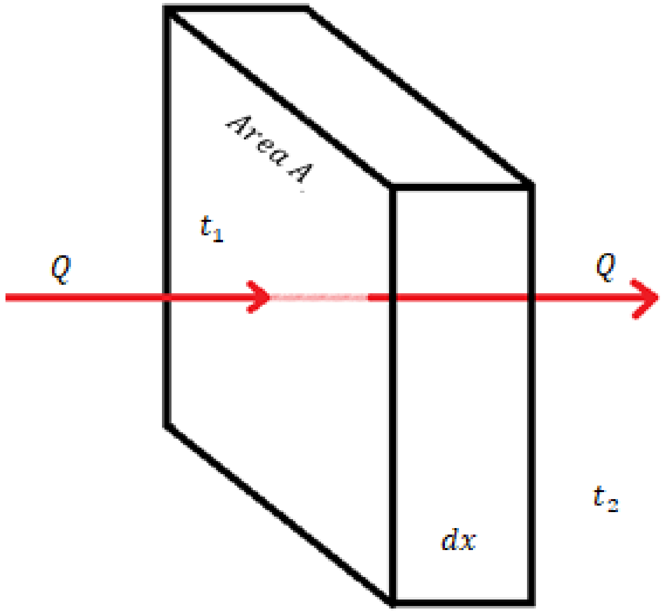
Fourier's Law

- Law of heat conduction
- Fourier's law of thermal conduction states that the time rate of heat transfer through a material is proportional to the negative gradient in the Temperature and to the area at right angles of that gradient through which the heat flows

$$Q \alpha\ A \nabla T$$

$$Q \alpha\ A \frac{dT}{dx}$$

$$Q = -k\ A \frac{dT}{dx}$$



Fourier's Law

Q=Heat transferred in watts/m2

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

A = cross section area in m^2
t = Thickness of the plate in metre
T1 &T2 = Temperatures of two faces in K
K = Coefficient of thermal conductivity in watts/mK
T = Time duration

Convection

- Convection is the transfer of heat from one place to another by the movement of fluids
- Rate of heat transfer depend upon difference in the fluid density at different temperature
- Convection is usually the dominant form of heat transfer in liquids and gases

$$H=a(T_1-T_2)^b \text{ in } W/m^2$$

- Where a and b are constants whose value depend on the type of heating surface

For vertical surfaces

$$\text{Heat Dissipation (H)} = 3.875\ (T1-T2)^{1.25}\ W/m^2$$

Radiation

- Heat is transferred from one body to other without actually heating the medium in between, its depend on the surface
- Rate of heat transfer is given by **Stephan's law**

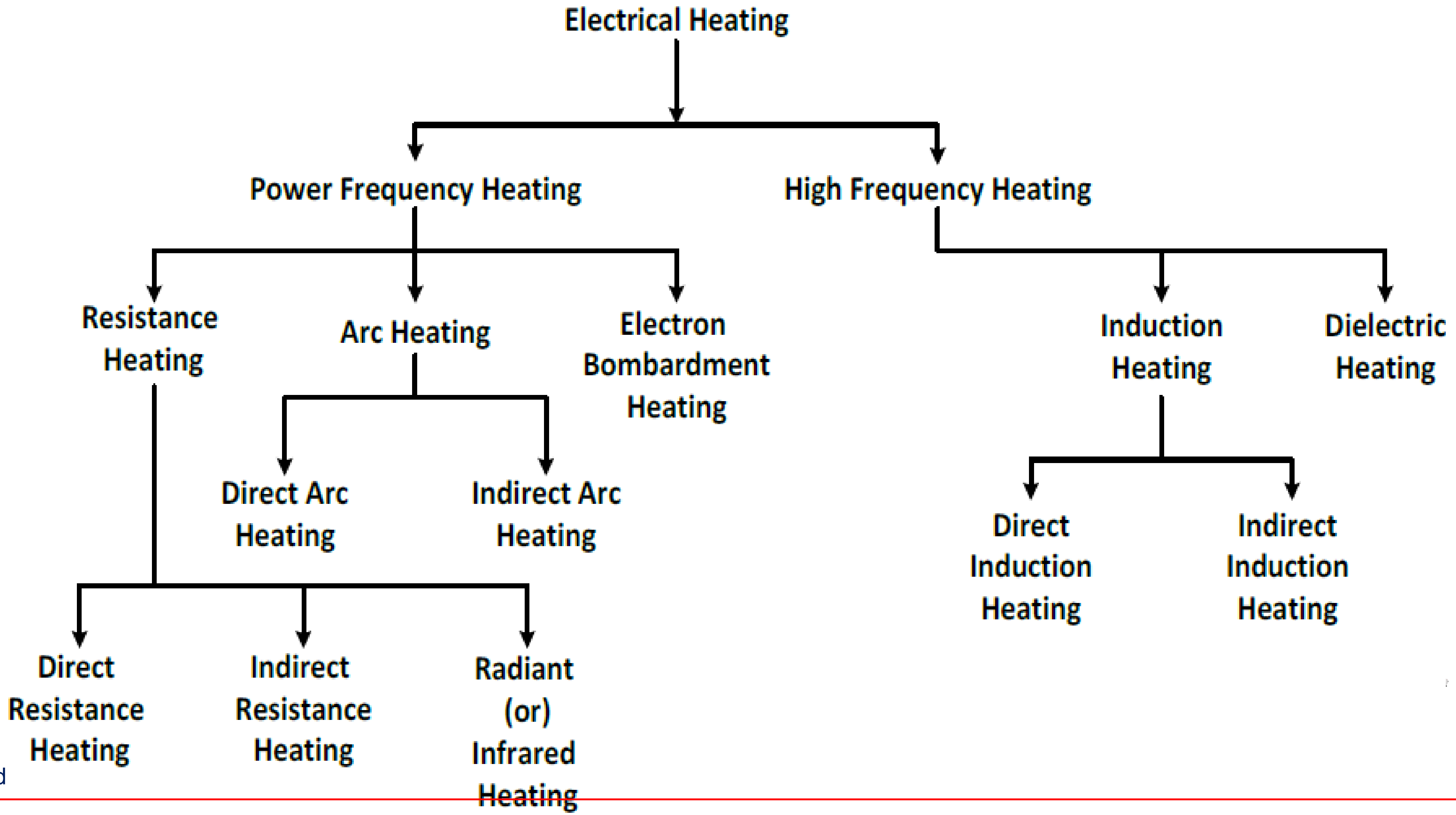
Energy radiated by a black body is proportional to 4th power of its temperature

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

K = constant known as radiant efficiency
e = Emissivity

Classification of Electrical Heating

Classroom Slides Set-1



Electrical heating can be broadly classified under two categories

1. Power frequency heating in which the furnace operates with 50Hz AC supply

2. **High-frequency heating**

- The frequency range used in this heating ranges from 10 MHz to 20 MHz
  The range of voltage changes from 10 – 20 kV
- High frequency heating require special high frequency generators
- This heating method utilizes electromagnetic energy to heat the suitable materials

- High-frequency heating is also named Radio frequency/dielectric heating, microwave & IR heating

Power Frequency Heating

A) Electric Resistance Heating

Electric Resistance Heating is defined as "the heat produced by passing an electric current through a material that has high resistance." As the current passes through the material, ohmic losses (**I^2R losses**) occur. These losses cause the conversion of electrical energy into heat

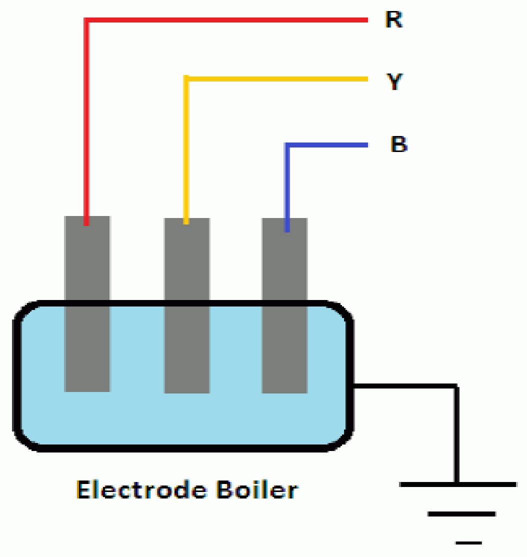
There are two methods of electric resistance heating

1. Direct electric resistance heating
2. Indirect electric resistance heating

Direct Electric Resistance Heating

Classroom Slides Set-1

- In direct electric resistance heating, the current is passed directly through the material that has to be heated
- While electrical current passing through material produce I^2R loss which appeared in the form of heat
- Current is passed through the fluid to be heated via electrodes



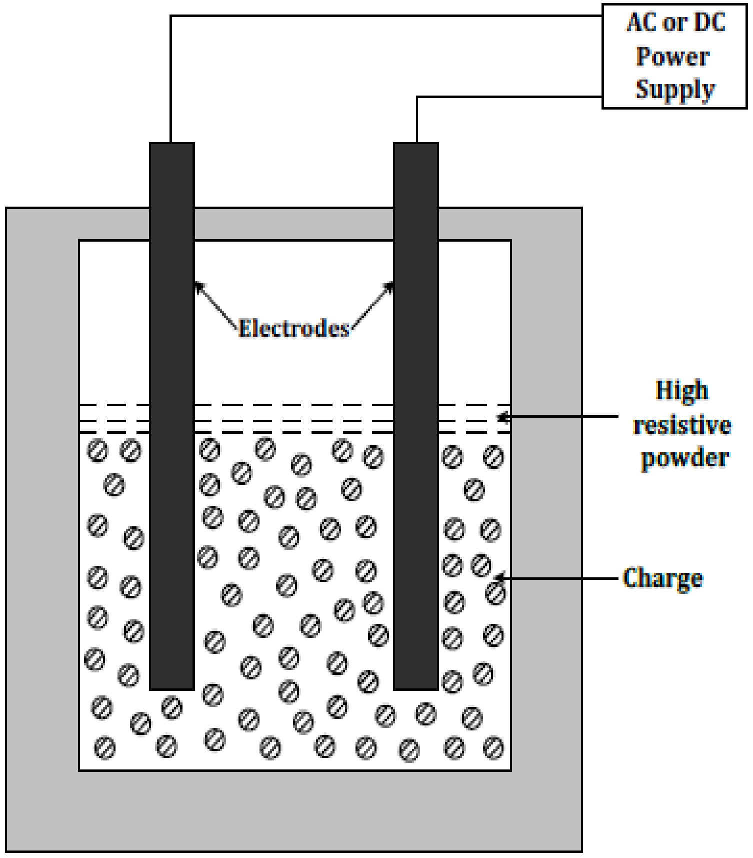


Fig. Direct Heating

Important for KPSC

Direct Electric Resistance Heating

- In this method, electrodes are immersed in a material or charge to be heated
- The charge may be in the form of powder, pieces or liquid
- The electrodes are connected to AC or DC supply
- In case of DC or 1-Φ supply , two electrodes are immersed & three electrodes are immersed in the charge and connected to supply in case of availability of 3-Φ supply
- When metal pieces are to be heated, the powder of highly resistive is sprinkled over the surface of the charge (or) pieces to avoid direct short circuit between electrodes
- The current flows through the charge and heat is produced in the charge itself. So, this method has high efficiency
- As the current in this case is not variable, so that automatic temperature control is not possible
- This method of heating is employed in salt bath furnace and electrode boiler for heating water

Advantages of Direct electric resistance heating

- High efficiency as the heat is directly produced in the charge
- Uniform heating
- High temperature can be obtained

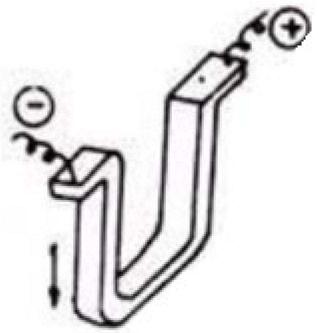
Applications

- Salt bath furnaces
- Resistance welding
- Electrode boiler for heating water

 # Applications of all Heating techniques are Important for KPSC

 # Important for KPSC

Salt Bath Furnace



- It consists of a molten salt such as Sodium Chloride (Nitrates, Nitrites, Caustic Soda, Chlorides, Carbonates, Cyanide)

- In which two electrodes are immersed

- A salt bath having 1000°C can be heated up to 1500°C

- AC supply is used

- DC supply is not used as it causes electrolysis

- Volt-20V and current vary from a few amperes to 3000A depending on furnace and charge to be heated

- Power input depend on the depth of immersion an the distance between the electrodes

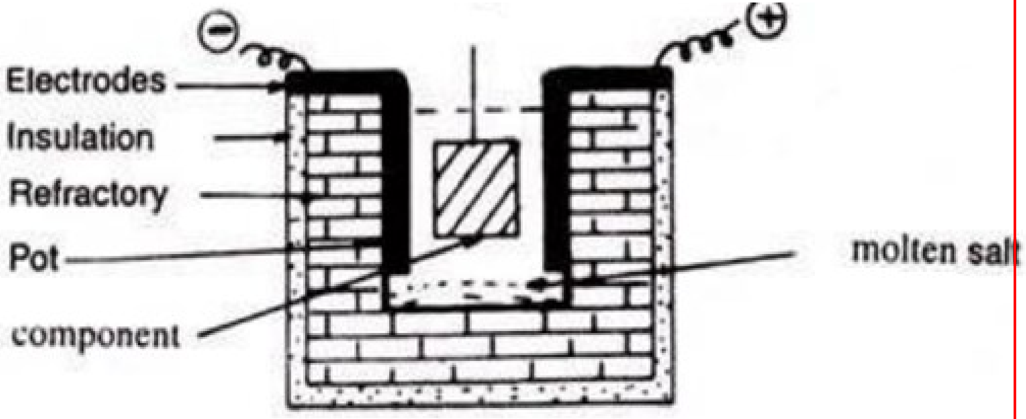


Fig. Salt Bath Furnace

Advantages of salt bath heating

- Rapidity of heating
- Uniformity of heating
- Possibility of selective localized heating
- Absence of oxidation

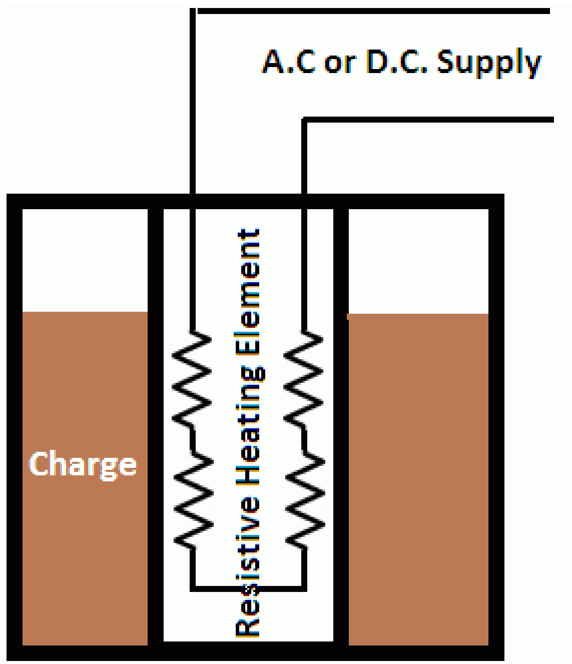
Fig. Salt Bath Furnace

Indirect Electric Resistance Heating

Classroom Slides Set-1

In Indirect electric resistance heating, the current is passed through a highly resistive material placed inside an oven

In the indirect resistance heating, the current does not flow through the body to be heated but it flows through the resistance elements which get heated up. The heat is then transferred from the heating element to the charge mainly by radiation or convection



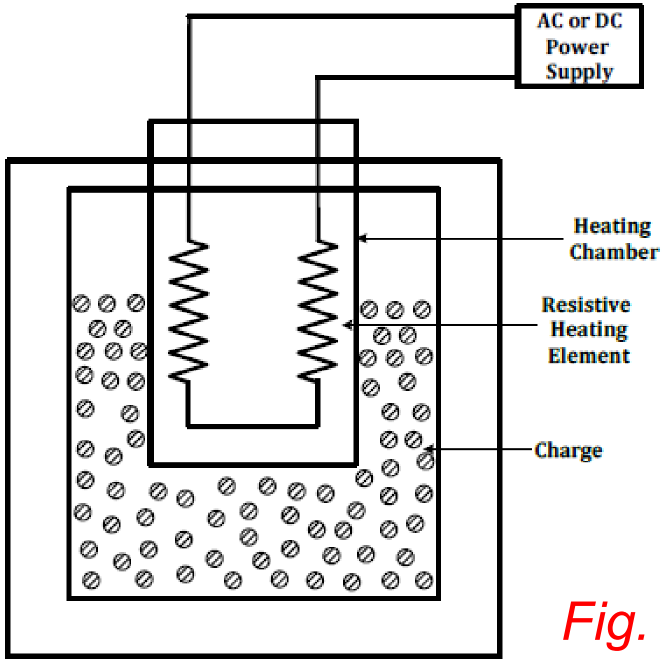


Fig. Indirect Heating

Indirect Electric Resistance Heating

Classroom Slides Set-1

- In this method of heating, electric current is passed through a wire or other high resistance material forming a heating element
- The heat proportional to I^2R loss produced in the heating element is delivered to the charge by one or more of the modes of transfer of heat i.e. convection and radiation
- An enclosure known as heating chamber is required for heat transfer by radiation and convection for the charge
- 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

Application of Indirect Electric Resistance Heating

Classroom Slides Set-1

- Room heater
- Immersion water heater
- Various type of resistance oven employed in domestic and commercial cooking

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

Advantage

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- Automatic control can be provided
- This arrangement can provide uniform temperature

 # Applications of all Heating techniques are Important for KPSC

Resistance Ovens and Furnaces

An electric furnace in which the heat is developed by the passage of current through a suitable internal resistance that may be the charge itself, a resistor embedded in the charge, or a resistor surrounding the charge. Also known as electric resistance furnace and electrical resistance oven

Resistance furnaces are classified according to their operating temperature

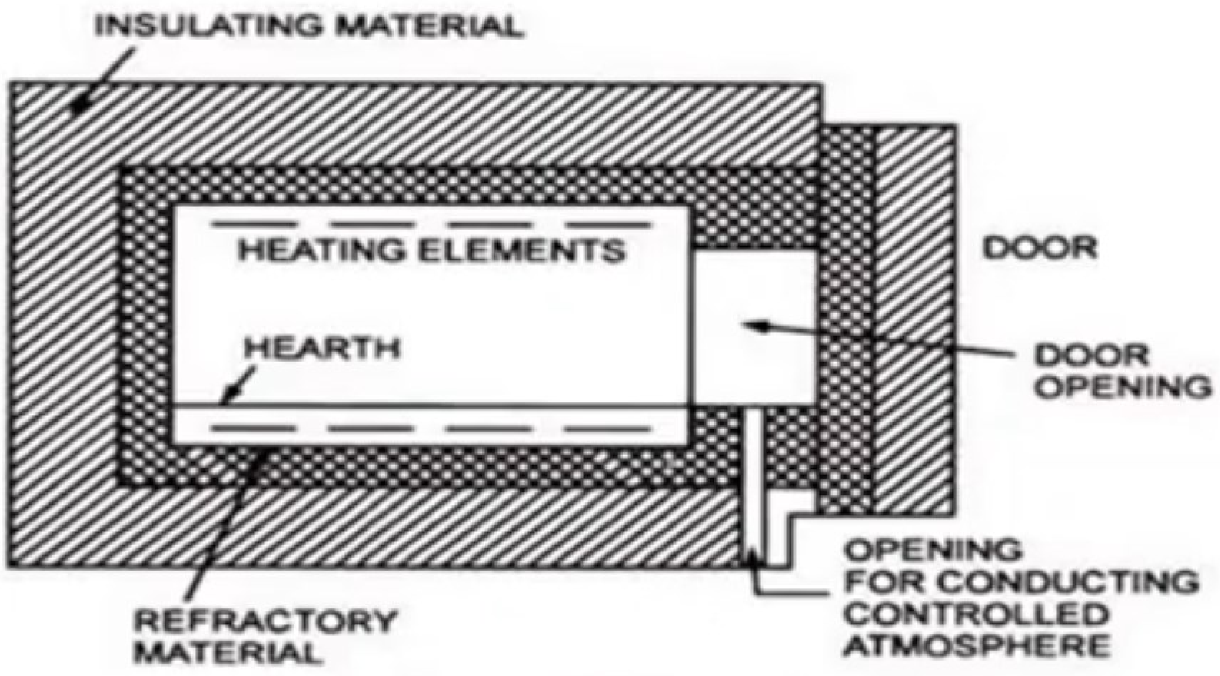
1. Low temperature
2. Medium temperature
3. High temperature

- Low temperature (up to 300°C) is consider as the resistance oven, here ventilation is also provided
- Resistance ovens are used for drying and baking potteries drying varnish coating, hardening of synthetic material
- Medium temperature furnaces (300°c to 1050°c)
- Annealing of steel and non- ferrous metals
- Melting of non- ferrous metals
- High temperature furnaces (1050°c to 1350°c)
- For hardening application

Resistance furnaces are classified according to their operating temperature

Classroom Slides Set-1

1. Low temperature
2. Medium temperature
3. High temperature



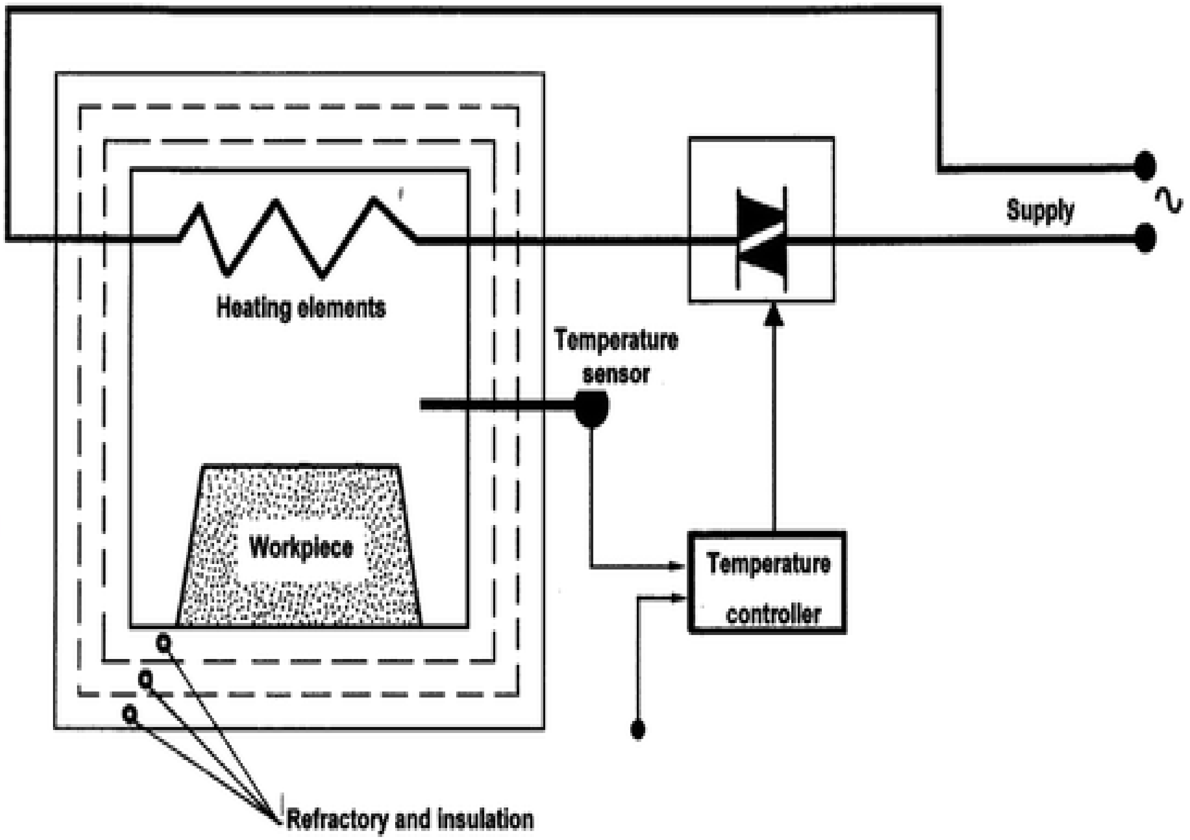


Fig: Resistance Ovens and Furnaces

Good Heating element: Desired 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

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

Good Heating element: Desired Properties

Classroom Slides Set-1

High mechanical strength

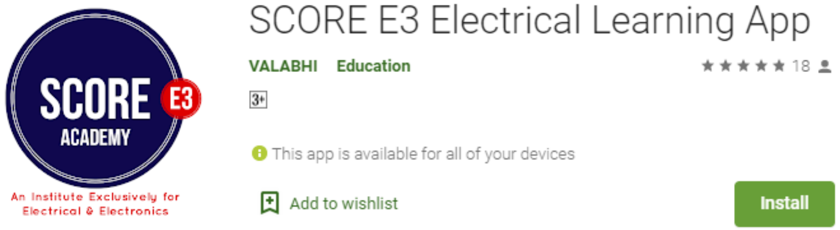
The material should have high-mechanical strength and should withstand for mechanical vibrations

Non corrosive

The element should not corrode when exposed to atmosphere or any other chemical fumes

Economic

The cost of material should not be so high and easily available



Heating Elements : Commonly used

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Heating Element	Operating Temp	Melting point
Nichrome Ni, Cr	1150 °C	1400°C
Nichrome Ni, Cr ,Fe	900°C	
Silicon carbide	1600°C	2830°C
Alloy of Tungsten	2000°C	3422°C
Molybdenum	1650°C	2623°C
Graphite	3000°C	3600°C

 # Important for KPSC

Design of resistance heating element

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

Circular Wire

d=Diameter of conductor
l=Length of conductor
ρ=Resistivity of conductor material

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

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

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

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

At steady temperature electrical power input is equal to heat output

H=Heat dissipated/Unit area

Surface Area, S $S = \pi d l$

Power Input =Heat Dissipated

P= $\pi d l H$

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

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

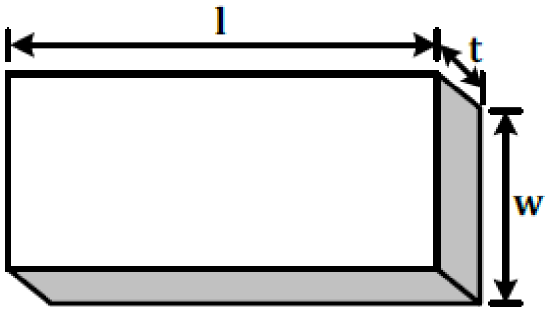
$$\frac{l}{d^2} = \frac{\pi V^2}{4\rho P}$$

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

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

Rectangular (Ribbon) wire

w = width of conductor
l = Length of conductor
t = thickness of conductor



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

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

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

Classroom Slides Set-1

At steady temperature electrical power input is equal to heat output

$$S = 2wl + 2(tl + tw)$$

Surface Area, S =2wl

Neglecting the side area 2(tl+tw) as the thickness is negligible

At Steady state temperature

H=Heat dissipated/Unit area

Power Input =Heat Dissipated

P=2wlH

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

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

$$\frac{t}{l^2} = \frac{2\rho H}{V^2}$$

$$\frac{t}{l^2} = \frac{2\rho H}{V^2} \rightarrow \text{(B)}$$

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

Temperature control of resistance furnaces / ovens

Classroom Slides Set-1

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

Temperature can be control in three method

1. By varying the applied voltage to the elements or current flowing through the element
2. By varying the resistance of elements
3. By varying the ratio of on and off times of supply

Classroom Slides Set-1

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

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

2. By varying the resistance of elements

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

Use of variable number of element

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

Change of connections

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

3. By varying the ratio of ON and OFF times of supply

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

Radiant or Infrared Heating

Classr 1

- Heat energy from an electric lamp is focused on the charge to be heated
- The heat energy is transferred through electromagnetic radiations
- A tungsten filament special type of lamp is used
- It is operated at the temperature of 2300°C
- At this temperature the lamp emits a large amount of infra-red radiations
- If we compare other types of resistance heating this lamp emits large amount of heat which is being reflected to the charge
- These lamps with reflectors are mounted on the sides of walls or sometimes on the top
- It does not permit the heat to leak through the surface of the chamber and hence heat insulation is not necessary.

- The reflectors are used and these are coated by Rhodium which increases heat emission intensities up to 7500 W/m^2

- Heat absorbed by the charge is about 4300 W/m^2
- Charge temperature is in between 200°C to 300°C

Applications of infra-red heating

- In paint drying industries for drying paints
- In the foundry sections of industry for moulding
- De-hydration at low temperatures.
- Heating of plastics at low temperatures

Fig: Radiant / Infrared Heaters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