I Electric Heating :-

Ref. books :- 1) UEPRET by G.C. Garg
3) A course in electric power by Soni, Gupta & Bhatnagar.
4) UEP & traction by J.B. Gupta

Electric heating is preferred over other methods of heating i.e, by wood, liquid fuel like kerosene & gas (LPG). There are 3 modes of transmission of heat.
i) Conduction ii) Convection iii) Radiation

Electric heating is based on the principle that when the electric current is passed through a medium, heat is produced.

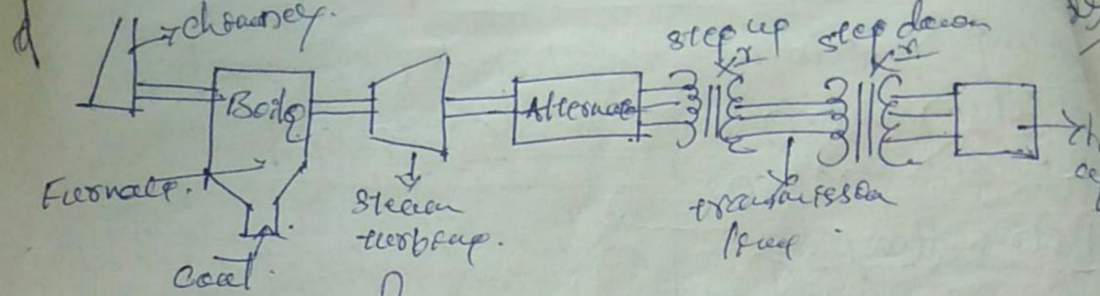
Let us consider the case of solid material which has res. R & carrying current of I amp. for 't' sec. then the heat produced is given by,

$$H = I^2 R t \text{ joules} = .24 I^2 R t \text{ calories}$$

Electric heating is used for domestic as well as for industrial applications.

I) Domestic applications of electric heating :-
i) ~~Room hea~~ water heating.
ii) Room heating.
iii) For cooking. iv) Electric Iron.
v) Electric ovens for baking, etc.

II) Industrial applications.-
i) Melting of metals. ii) Electric welding.
iii) Moulding of glass & plastics.
iv) Heat treatment of metals like ~~anneal~~ tempering, soldering, hardening, etc.
v) Enamelling of Cu conductor.



Advantages of electric heating :-

i) Clean & neat atmosphere :- There is no coal dust or smoke while operating with the electric heating method.

ii) No pollution :- Absence of flue gases does not result in pollution of air.

iii) Controlled temp :- The temp can be controlled within the limit of ± 5°C which is not possible in non-electrical heating process.

iv) Ease of control :- The heating can be started & stopped instantaneously.

v) Localised application :- A workpiece can be heated upto a particular place for heat treatment.

vi) Low ambient temp :- The temp. around an electrical furnace is much lower as compared to that around non-electrical furnace which is troublesome for workers.

vii) Uniform heating :- Uniform heating takes place through induction heating.

viii) Heating of bad conductors of heat & electricity :-

ix) Highest η of utilization :-

x) Cheap furnaces :-

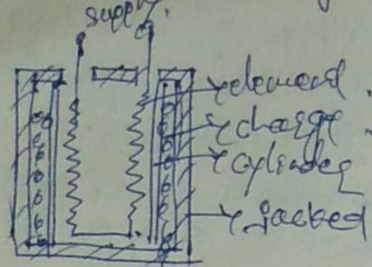
Classification of Heating Methods

Based on the temp. for which the materials are to be heated, there are different heating methods.

~~12/08/2008 – 8, 26.33~~

1) Low temp upto 400°C
2) Medium " 400–1150°C
3) High temp – Temp above 1150°C

Indirect res. heating:—

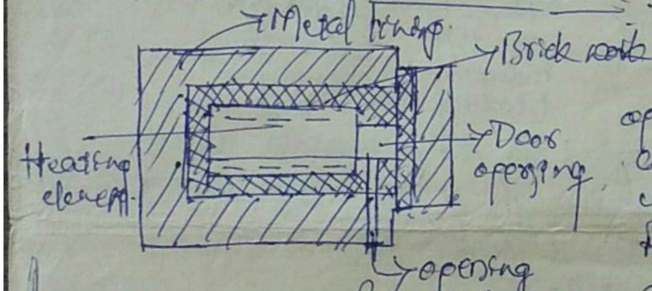


eg:— room heater, hair drier, resistance oven (electric [illegible]

Here, the electric C^n is passed through an element of high res. Passage of electric C^n through res. produces I^2R loss which appears in the form of heat. Heat is then transferred from heating element to the charge by means of radiation & convection. It also works with DC as well as AC power supply.

Advantage:- i) Automatic temp control is possible.
ii) Uniform heating can be done.

Resistance furnace or oven:



Res. furnaces may be classified according to their operating temp. High temp heating chambers with provision for ventilation is termed as oven. Res. ovens are used for drying & baking of pottery, commercial & domestic cooking, heat treatment of metals, etc. In medium temp ovens, the operating temp is bet 300°C to 1050°C
In high " " " " " " 1050°C " 1350°C
Temp. upto 1000°C can be attained in ovens using high res. wire elements. The heating elements are generally the alloys of Ni, Cr & Fe. However, by using the element made up of graphite, temp upto 3000°C can be attained. Heating element may be either in the form of ckt wire or rectangular ribbon. The oven is made up of metal frame with the internal lining of fire bricks. Depending upon the use, the heating element may be placed either on the top or bottom or sides of the oven.

13/08/08:- 2, 9, 13, 31, 33.

element material :- The material of the heating element should have the following properties.

(1) i) High specific res :- It should have high sp. res so that only a small quantity of wire is reqd to produce large amount of heat. ($\because R = \rho \frac{l}{a} \Rightarrow \rho = \frac{Ra}{l}$)

(3) ii) High melting pt :- Its melting pt. should be sufficiently higher than its operating temp. Otherwise small rise in temp will destroy the element.

(4) iii) High oxidizing temp :- Its oxidizing temp should be higher than its operating temp. Otherwise, the oxidised layers on the surface of the element will alter the res. of the material.

iv) Low temp. co-eff. of res :- (1). Since res. of a conducting element varies with the temp, it should have low temp co-eff of res. so that the res. does not change with the temp.

(2) +ve Coefficient of res.

(6) v) High ductility & flexibility.

(7) vi) Should withstand vibrations.

(8) vii) Anti-corrosive :- (9) Mechanical Strength.

~~Heating alloys~~ :-
- 1) Constantan → Ni 45%, Cu 55%, 400°C
- 2) Nichrome → Ni 80%, Cr 20%, 1500°C
- 3) Kanthal → Cr, Al, Cobalt, Iron, 1300°C
- 4) Silicon Carbide 1450°C.

Causes of failure of heating elements :-

With the passage of time, the heating element will damage. Some factors responsible for failure are,

1) Formation of hot spots 2) Oxidation
3) Corrosion 4) Mechanical failure.

1) Formation of hot spots :-

At ~~some~~ particular place of ~~an~~ a heating element will shine brighter during the operation. ~~Failure occurs at these points.~~ At these points the operating temp is much higher than rest of the filament. The failure occurs at these points.

The formation of hot spots is due to

a) Unequal spacing :- If the spacing of the different part of the element is non uniform, the dissip... will be highest where the spacing is minimum. This results in the formation of hot spot.

b) Shielding by supporting N/W :- If the supporting structure is a bad conductor of heat & resist the flow of heat, the temp of the element will remain high near the supports. This will result into the formation of hot spots.

c) Excessive oxidation :- The portion of the element undergoing excessive oxidation w.r.t. the rest of the element offers high res. to the flow of C^n. The heat produced in this portion is high, thus resulting into hot spot.

2) Oxidation :- The exposed surface of the element gets oxidised at high temp. Later on, the exposed surface gets flaked off, ~~exposing~~ during the operation thus exposing the inner surface to the atmosphere. In this way the C/s area of the element will decrease, thus resulting into the formation of hot spots.

3) Corrosion :-

4) Mechanical failure :-

Design of heating element :-

By knowing the electrical i/p power & its volt, the size & length of the wire of ~~to~~ the heating element can be calculated to produce the heat. The wire used may be circular or rectangular like ribbon. Considering, an ideal heating element on reaching its steady temp. will dissipate the heat which is equal to i/p power. Generally heat ~~will be~~ dissipated from the heating element at high temp is by radiation.

$= 5.72$ ...

dissipated by radiation according to Stefan's law,

$H = 5.72 K \cdot e \left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4 \right] W/m^2$

where, T_1 is temp of the source of heat in °C

T_2 " " , " substance to be heated in °C

K is constant known as radiant 'η'. K = 1 for single element & K = .5 - .8 for several elements placed side by side. e = emissivity

e = 1 for black body

e = .9 for res. heating elements.

WKT,

$P = VI = \frac{V^2}{R}$

where 'V' is the supply volt & 'R' is the res. of the heating element.

WKT,

$R = \frac{\rho l}{a} = \frac{\rho l}{\frac{\pi d^2}{4}} = \frac{4\rho l}{\pi d^2}$ for a cir. wire of diameter 'd' & length 'l'.

Now,

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

$\Rightarrow \frac{l}{d^2} = \frac{\pi V^2}{4\rho P} \longrightarrow (1)$

Now

surface area, $S = 2\pi r l = \pi d l$.

& Heat dissipated $= \pi d l . H$.

Since, at steady temp,

Power i/p = heat dissipated.

$P = \pi d l . H$.

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

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

By solving eqⁿ (1) & (2) length & diameter of the wire can be determined.

For ribbon type of conductor, let 'w' be the ~~length~~ width & 't' be the thickness.

18/08/08 :- 2, 5, 20, 21, 22, 23, 29

Power i/p, $P = \frac{V^2}{R} = \frac{V^2}{S l/a} = \frac{V^2}{S l/wt} = \frac{V^2 wt}{S l}$

or, $\frac{l}{wt} = \frac{V^2}{PS}$ → (3).

Since, at steady temp.,

i/p power = heat dissipated.

$P = 2wl.H$ (neglecting the side area 2tl as the thickness is negligible)

⇒ $\frac{V^2 wt}{S l} = 2wl.H$.

⇒ $\frac{t}{l^2} = \frac{2HS}{V^2}$ → (4).

By solving eqns (3) & (4), length & width 'w' for a ribbon of thickness 't' will be calculated.

η & losses:—

In res. furnace the useful heat is the heat reqd to raise the temp of charge. ~~to reqd~~

Heat loss occurs in the furnace due to

i) heat used in raising the temp of oven (h_{l1})

ii) " " " " " " " " container (h_{l2})

iii) heat conducted through walls (h_{l3})

iv) Escapement of heat due to opening of door (h_{l4})

$\eta =$ ~~Heat~~ $\frac{o/p}{i/p} = \frac{o/p}{o/p + losses} = \frac{\text{Heat reqd to raise the temp of charge to reqd value}}{\text{" + losses}}$

The Heat reqd to raise the temp of charge is given by, w = Mass of charge in kg × sp. heat of charge in J/kg/°C × temp rise = MSt Joules.

Since, the heat is continuously conducted through walls, this heat loss is important.

∴ Heat loss by conduction through walls $= \frac{KA}{t}(T_1 - T_2)$ MJ/hr

K – thermal conductivity in MJ/Hr/m²/m

·575 to 1·15 MJ/m² of the door area, if the door is opened for a period of 20–30 secs. η of furnace is 60–80%

Control of Res. ovens:—

Temp control is necessary in res. ovens. Hence, temp may have to be kept constant or varied according to the requirement. Control may be manual or automatic. To control the temp of res. oven we have to vary the C^t through res. oven.

Methods of control:—

i) By use of variable no. of heating elements.
ii) Series – ||

ii) Series – parallel or Y – Δ connection of the heating elements.
iii) External series res.
iv) Transformer tappings:—

Automatic control:— If we want to control the temp of the res. oven automatically, some form of thermostat must be used. When the temp exceeds or falls below some predetermined value, thermostat operates the relay which varies the C^t through the heating element. thus by maintaining const. temp.

Special types of res. furnaces:—

1) Air-circulation furnace.
2) Bright annealing "

1) **Air Circulation furnace:—**

The charge may not get uniformly heated in an ordinary furnace in which heat transfer takes place by radiation. If uniform distribution of heat is reqd, air circulation furnace must be used. Applications are heat treatment of Al & light metals. In such furnace air is passed over the heating element & this heated air is circulated through the charge, thus imparting the heat uniformly to all parts of the charge by conduction.

2) Bright annealing furnace:- The process of gradual cooling a heated material for removing its brittleness known as annealing. In the ordinary annealing process, a scale of oxide is formed over the surface of the material. So this oxide scale must be removed in order to have bright finish. The formation of oxide scale can be prevented if annealing process is carried out in an atmosphere free from oxygen, water vapour & CO_2. Such a condition can be achieved by heating the material in an air tight furnace, which is known as bright annealing furnace.

1) $\frac{1}{d^2} = \frac{\pi \rho V^2}{4SP} =$

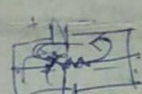
$H = 5.72 K e \left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4 \right] W/m^2$

$= .$

WKT, at steady temp heat dissipated = i/p power

$\pi d l \times H = P.$

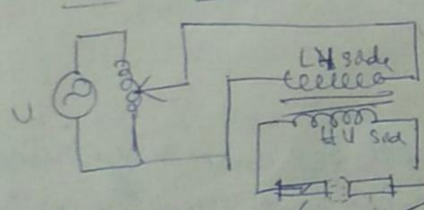
$d^2 l^2 = 2$



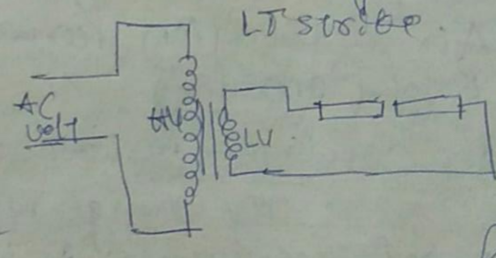
Arc furnaces:-

The furnaces used for melting

HT strike:

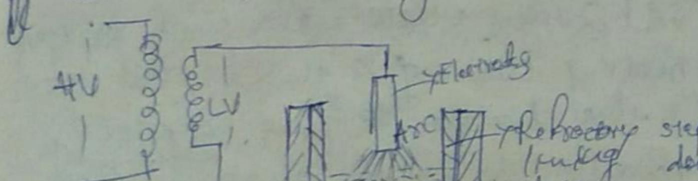


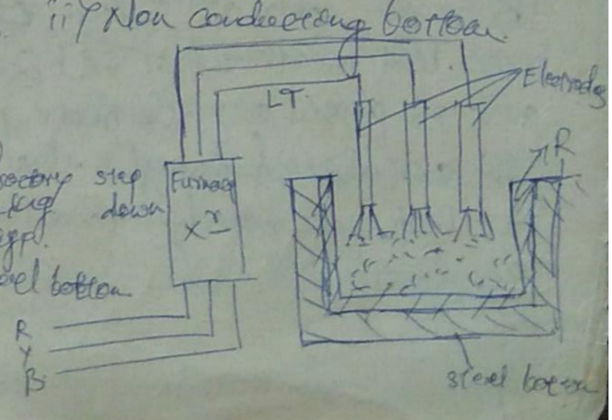
LT strike.



I) Direct arc furnace & II) Indirect arc furnace.

Direct: i) Conducting bottom ii) Non conducting bottom





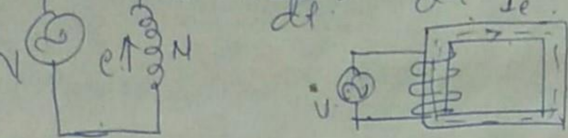
the electrodes. for which the i/p power of furnace is max.

Induction heating :-

Introduction :- i) Eddy currents & ii) Hysteresis loss

i) Eddy C^ts :-

$e = -N\frac{d\phi}{dt} = -L\frac{di}{dt}$ I_e $P = i^2R$



a) $e \propto \frac{d\phi}{dt} \Rightarrow i \propto \frac{d\phi}{dt} \propto f \Rightarrow heat \propto i^2 \propto f^2$

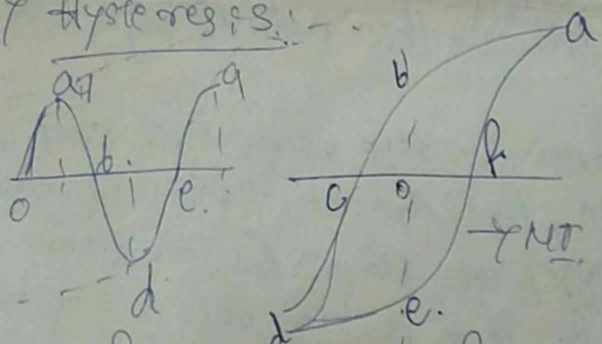
b) $B = \mu_0\mu_r H$, $H = \frac{NI}{l} \Rightarrow Heat \propto \mu_r$.

c) $\phi B \propto N \Rightarrow heating \propto N$ d) heat $\propto$ supply I

d) Lesser is the resistivity, greater is the C^t $\Rightarrow \uparrow$ heating

e) $W_e = KB_{max}^2 f^2$

ii) Hysteresis :-



a) $f\uparrow \Rightarrow$ large no. of loops are produced.

b) $W_h = KB_{max}^{1.6} f$ c) $[B = \mu_0\mu_r H]$

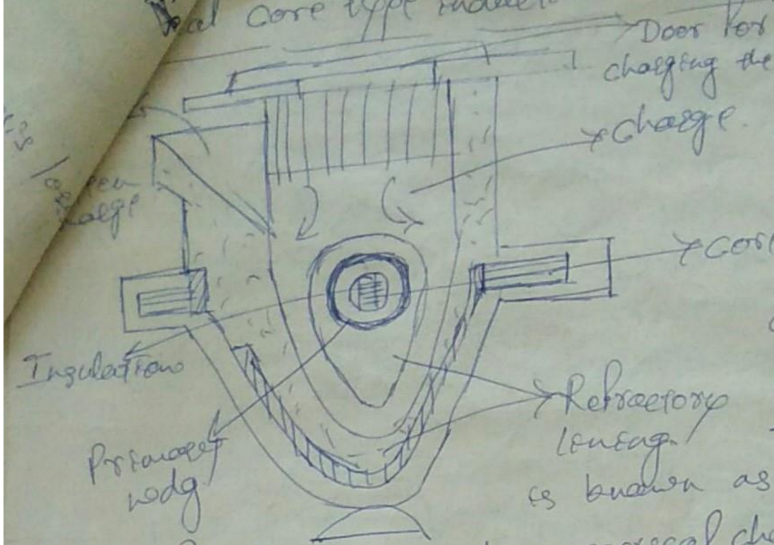
c) Curie temp :-

Low frequency Induction heating :-

for melting & refining of metals

i) Core type :- a) Direct core type b) Vertical core type c) Indirect core

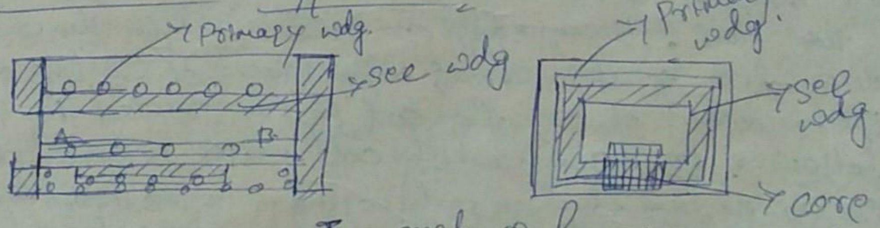
Vertical core type induction furnace:-



In order to overcome the drawbacks of direct core type induction furnace, an improved type of furnace was found by Ajax Wyatt. Hence the furnace is known as Ajax Wyatt vertical core furnace. It has vertical channel for the charge & also the hearth is vertical. When the power supply is given to the primary wdg, due to the mutual induction the C^n flows through the annular hearth which acts as secondary. Thus the charge (metal pieces) is heated. Also, the heat transfer takes place due to the eddy C^n loss & hysteresis loss.

Since, it provides good magnetic coupling it has low leakage reactance & high i/p power, so it can operate on normal frequency power supply. When, the molten metal is taken out through the exhaust door, & fresh charge (metal pieces) are poured into the hearth through another door. In this way continuous operation takes place in this furnace.

Indirect core type I.F:-

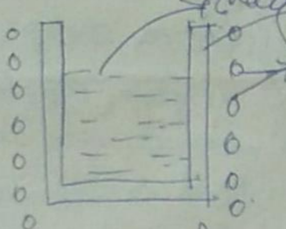


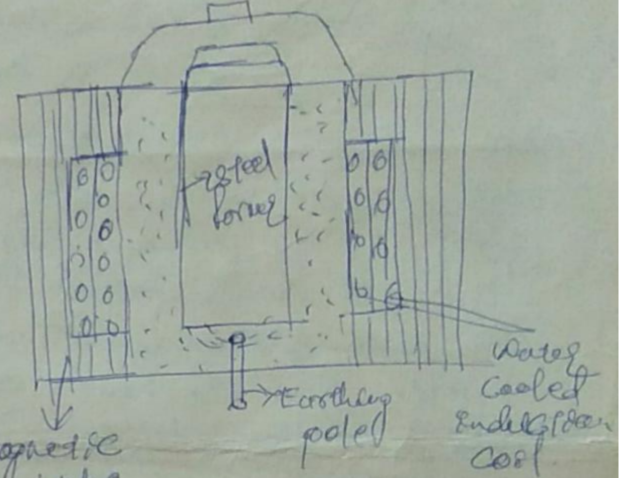
In such a furnace an inductively heated element is made to transfer the heat by radiation. In this type, the principle of induction has been utilised for providing the heat.

It consists of an iron core linking

with the primary as well as sec. wdg. Here, the me[tal] container acts as the sec. wdg. Primary wdg is co[nnected] to the AC supply & hence, induces the C^{n} & thus [heats] the metal container. Heat is transmitted to charge [by] radiation. It is advantageous because there is [no] need of external control equipment. It consists of part AB of the magnetic ckt which is made up of special alloy. It looses its magnetic property at a particular high temp & regains them when cooled to the same temp.

Coreless type IF :-





The flux produced by the primary wdg sets up eddy C^{ns} in the charge. The eddy C^{n} developed is given by,

$I_e \propto B^2 . f^2$ where B- f-

These eddy C^{ns} are sufficient to heat the metal to melting point & also sets up electromagnetic forces which produce stirring action.

The furnace has refractory lining.

The primary coils are wound around it. The alternating flux is produced by the primary wdg. A laminated magnetic yoke is provided outside the induction coil to provide a definite path for the flux. Hence, eddy C^{n} is induced for the charge. At high temp, due to skin effect some amount of Cu loss occurs in the coil. To avoid this, the coil is constructed in the form of hollow tube through which cold water is circulated.

Advantages :- 1) The time taken to reach melting pt is less in this furnace. 2) Precise control of power into the charge. 3) Crucible of any shape can be used. 4) Charging & pouring is simple. 5) There is no dust, smoke & noise. 6) Automatic stirring in the charge due to eddy C^{n}. 7) Erection ~~Operating~~ cost is low.

The choice of freq. of operation is governed by the factors material to be heated & thickness of the cylinder (crucible) layer. The freq. of the supply can be determined by using penetration formula. Accordingly,

$$t = \frac{1}{2\pi}\sqrt{\frac{\rho \times 10^7}{\mu f}} \text{ m.}$$

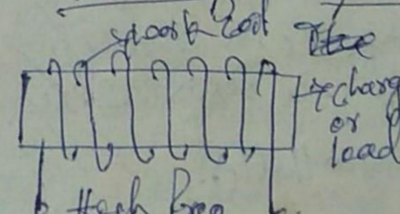
where, ρ – is the res. of molten metal in Ω-m.
f – " " supply freq. in Hz
μ – Relative permeability (μ=1 for molten steel)

For efficient operation the ratio $\frac{r}{t}$ (i.e, the ratio of radius of pieces of material used as charge to the thickness of crucible) should be greater than 3. If it is taken as 4, then the expression for the freq. for efficient operation, becomes,

$$f = \frac{1}{4\pi^2} \times \frac{\rho \times 10^7 \times 16}{\mu \times r^2}$$

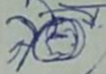
In the above expression we can see that by increasing 'r' efficient operation can be obtained with lower frequencies. In most of the modern coreless induction furnaces, the frequencies in the range of 500 to 1000 Hz are used. However, for smaller units for melting small quantities of finely divided metal frequencies upto 100 kHz to 1000 kHz are used.

High freq. eddy C^n heating (induction heating):-

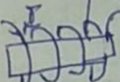


The material to be heated is placed within a high freq. C^n carrying coil, alternating flux is produced & eddy C^ns are induced in the material. Hence, heat is produced. The high freq. C^n carrying coil is known as heater coil or work coil, the material to be heated is known as the charge or load & the process is known as high freq. eddy C^n heating.

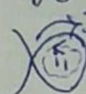
Since, $I_e \propto B^2 f^2$, by increasing the freq. of the supply, we can increase the eddy C^n & hence heat produced. However, it is observed that, higher freq. of the supply, the greater will be the tendency of the induced eddy C^n to remain at the surface of the material being heated. This property is called skin effect. (Refer skin effect from G.C. Garg)



Induced eddy C^n is high at the surface of the material to be heated & its value reduces as we go inside the depth of the material. Since, depth of penetration of eddy C^n into the material is



$$t = \frac{1}{2\pi}\sqrt{\frac{S \times 10^7}{\mu f}}$$



m, Hence, by using high freq. power supply, we can restrict the depth of penetration of eddy C^n to desired depth.

This effect is being utilized for heat treatment of surfaces of steel parts of m/c tools. Same effect allows the use of hollow conductors & to which water cooling is provided.

Characteristics of high freq. eddy C^n heating:—

i). The heat generated is closer to the outer surface & no heat is produced at the core.

ii). The depth of penetration is inversely proportional to the square root of the freq. & relative permeability of the material undergoing heating. It is directly proportional to the sq. root of the resistivity.

iii) The hot area & depth can be controllable.

iv) Rate of heating is high.

v). To prevent oxidation, we can introduce vacuum or inert gases into the heating chamber.

vi). Initial investment is high.

surface

Applications of high freq. induction heating:

i) Surface hardening of steel parts:-
The portion of the steel component to be hardened is covered with induction coil.

ii) Brazing:- Two pieces of different materials to be soldered can be soldered by using an alloy.

iii) Annealing:-

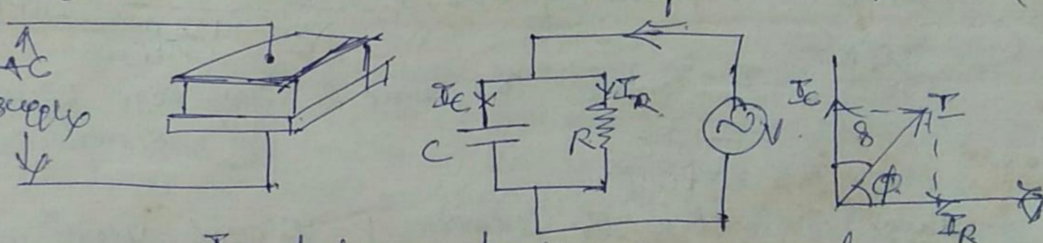
iv) Butt welding.

v) Sterilisation of medical instruments.

vi) Drying of metallic painted surfaces.

Dielectric heating:-

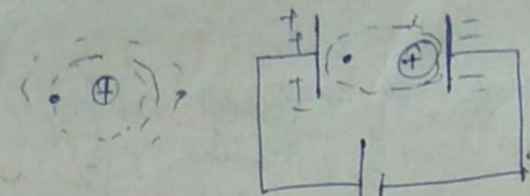
It is also called as high freq. capacitive heating. It is used for the heating of insulating materials like wood, plastic, etc. For producing sufficient heat the supply freq. of about 10-30MHz is used with the i/p volt of 20KV.



In dielectric heating, the material to be heated is kept in bet^n two conducting electrodes, which forms a capacitor. When AC supply is applied a/c the plates of a capacitor, the C^n drawn by the capacitor does not lead the volt exactly by 90°. The angle bet^n volt & C^n is slightly less than 90° i.e, δ (δ = 90 - φ) which is called as loss angle. It can be seen that there is a small resistive C^n component which is in phase with volt & produces power loss in the dielectric. This power loss appears in the form of heat energy in the dielectric material called as dielectric loss. The dielectric loss is directly proportional to the freq. of the supply. Also, the heat production in the dielectric material is due to the dipole movement.

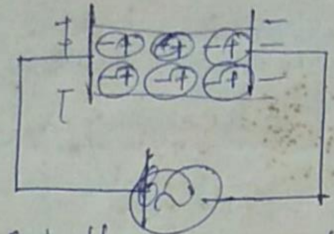
Characteristics of dielectric heating :-

Dipole formation :-



i) Heat is produced in the dielectric material itself. Hence, the uniform heating takes place.

ii) Heating will be faster with the increase in freq.



iii) Bad conductors of heat can only be heated by the dielectric heating method only.

iv) Heating can be started & stopped instantaneously.

v) Since, no flame appears highly flammable materials can be safely heated.

Calculation of amount of heat produced (Choice of freq & volt. reqd for dielectric heating) :-

As shown in the above fig. the insulating material to be heated is placed betⁿ two conducting electrodes to which high freq. ac supply is given. The capacitor thus formed is not a pure capacitor. Hence, as shown in the equivalent ckt dgm. let 'R' be the res. of the capa & 'C' be the capacitance of the capacitor. The phasor dgm is as shown in the fig. above.

The c= through the capacitor, $I_C = \frac{V}{X_C} = \frac{V}{1/2\pi fC} = 2\pi f C V$.

WKT, $I = I_C + I_R$ But, since R is very large I_R is very small & neglected.

$\therefore I \simeq I_C$.

i.e $I = 2\pi f C V$.

Power consumed in the dielectric $= P = VI\cos\phi = V(2\pi f C V)\cos\phi$
$= 2\pi f C V^2 \cos\phi$.

This power consumed is converted into heat.

In the above expression, $\cos\phi$ & C are constant for a given dielectric material. Hence, the heat produced is proportional to supply freq & volt. Hence, high freq & high volt is used for dielectric heating.

$C = \frac{\epsilon_r \epsilon_0 A}{t}$

Applications of dielectric heating :-

1) Plywood industry 2) Sand core baking. 3) Plastic industry 4) Tobacco industry 5) Bakeries. 6) Electronic sewing 7) Dehydration of food. 8) Removal of moisture from oil emulsions. 9) Electro-medical applications. 10) Book binding.

...e of plywood is to be heated by dielectric heating. The c/s of the piece is ·5 m^2 & the thickness is 2·5 cm. If freq. of 25 mega cycle per sec is used & the power absorbed is 1000 watt, find the volt. employed, necessary for heating. The relative permittivity of wood is 2·5 & ~~power~~ p.f. is ·046.

Soln:- Given:- $\epsilon_r = 2{\cdot}5$, $\epsilon_0 = 8{\cdot}854\times10^{-12}$ F/m, $A = {\cdot}5\, m^2$, $t = {\cdot}025$ m

$C = \frac{\epsilon_r \epsilon_0 A}{t} =$ ~~$637{\cdot}488\times10^{-12}$ F~~ 4427×10^{-12} F

$\cos\phi = {\cdot}046$, $f = 25$ MHz $= 25\times10^6$ Hz.

$\therefore P = 2\pi f C V^2 \cos\phi \Rightarrow V = \sqrt{\frac{P}{2\pi f C\cos\phi}} =$ ~~465·93 V~~ 559·12 V.

2) The power reqd for dielectric heating of a slab of resin 150 cm^2 in area & 2 cm thick is 200 W, freq of 30 MHz. The material has ϵ_r of 5 & p.f. of ·05. Determine the volt. necessary & C^n flowing through the material. If the volt. is limited to 600 V, what will be the value of freq. to obtain the same heating.

Soln:- Given:- $A = 150\, cm^2 = 150\times10^{-4} m^2$ & $t = 2\,cm = {\cdot}02$ m.

$C = \frac{\epsilon_0 \epsilon_r A}{t} = 33{\cdot}2\times10^{-12}$ F

$V = \sqrt{\frac{P}{2\pi f C\cos\phi}} = 800$ V. & $I = \frac{P}{V\cos\phi} = \frac{200}{800\times{\cdot}05} = 5$ A.

Now, heat produced $\propto f_1 V_1^2$.

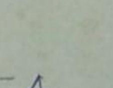
Also, $\quad$ " $\quad \propto f_2 V_2^2$

$\Rightarrow f_1 V_1^2 = f_2 V_2^2 \Rightarrow f_2 = f_1\left(\frac{V_1}{V_2}\right)^2 = 30\times10^6\times\left(\frac{800}{600}\right)^2 = 53{\cdot}3$ MHz

3). A cubic water tank has surface area of 6 m^2 & is filled to 90% capacity six times daily. The water is heated from 20°C to 65°C. The losses per square meter of tank surface per 1°C temp difference is 6·3 watts. Find the loading in KW & the η of the tank. Assume sp. heat of water = 4200 J/kg/°C & 1 KWhr = 3·6 MJ.

Soln:- Let, one side of the tank be 'l' m

Surface area of the tank $6l^2 = 6\,m^2 \Rightarrow l = 1$ m.



Volume of the tank $= l^3 = 1\,m^3$.

Water to be heated daily $= 6\times{\cdot}9\times1\,m^3 = 5{\cdot}4\,m^3 = 5400$ kg $\quad (\because 1\,m^3 = 1000$ kg$)$

Heat reqd to raise the temp. of water $= ms(t_2 - t_1) = 1020$ MJ $= 283{\cdot}5$ KWhr

Losses from the surface of the tank $= \frac{6{\cdot}3\times6\times45\times24}{1000}$ KWhr $= 40{\cdot}8$ KWhr.

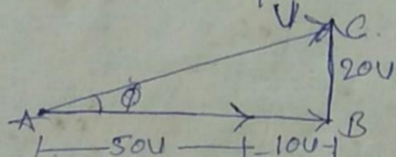
Energy supplied $= 283{\cdot}5 + 40{\cdot}8 = 324{\cdot}3$ KWhr.

Loading in KW $= \frac{324{\cdot}3}{24} = 13{\cdot}5$ KW.

$\eta = \frac{O/P}{...}$

4) A 3-ϕ electric arc furnace has the following
C^{t} drawn = 5000A
Arc volt = 50V
Res. of x^r reffered to sec = .002 Ω
Reactance " " " " = .004 Ω.
i) Calculate the p.f. & KW drawn from the supply.
ii) If the overall η of the furnace is 65%. Find the time reqd to melt 2 tonns of steel when latent heat of steel = 8.89 K.cal/kg
sp. heat of steel = .12, melting pt. of steel = 1370°C & initial temp. of steel = 20°C

Sol^n Given: Arc volt = 50V.
C^t drawn, I = 5000A.
Volt. drop. due to res. of x^r = 5000×.002 = 10V
" " " reactance " " = 5000×.004 = 20V
WKT, arc drop is resistive in nature.



∴ open ckt phase volt. of x^r sec
$V = \sqrt{(50+10)^2 + 20^2} = 63.25V$

i) $P.f = \cos\phi = \frac{AB}{AC} = \frac{50+10}{63.25} = .9487$
Power drawn per phase = $VI\cos\phi$
= 63.25×5000×.9487 = 300 KW
Total power drawn from the supply = 3×300 = 900KW.
ii) Energy reqd to melt 2 tonnes of steel = $mS(t_2-t_1) + mL$
= $m[S(t_2-t_1)+L]$
(1 cal = 4.18 J)
= 2000[.12×(1370−20)+8.89]
(1 KWhr = 3.6 MJ)
= 3,41,780 Kcal
= 1428640×10³ J = 1428.64 MJ
Now,
= 397.42 KWhr.
$\eta = \frac{o/p}{i/p} \Rightarrow o/p = .65 \times 900 = 585$ KW = Power reqd
Time reqd for melting = $\frac{\text{Energy reqd for melting}}{\text{Power " " "}} = \frac{397.42}{585}$
(1 hr 60 min)
.6793 hr ?
= .6793 hr.
= 40 minute 46 sec.
= 40.758 min
1 min – 60 sec
.758 min ?
= 46 sec

Find the η of a high freq. induction furnace which takes 10 min to melt 1.8 kg of aluminium. The i/p to the furnace being 5 kW & initial temp. 15°C.
sp. heat of Al = 880 J/kg/°C
Melting pt. of Al = 660°C
Latent heat of fusion of Al = 32 kJ/kg & 1 J = 2.78 × 10^{-7} kWhr.

Solⁿ: $m = 1.8$ kg, $t_1 = 15°C$, $t_2 = 660°C$, $S = 880$ J/kg/°C
$L = 32000$ J/kg
Heat reqd to melt 1.8 kg of Al $= mS(t_2 - t_1) + mL$
$= m[S(t_2 - t_1) + L]$
$= 1.8[880(660-15) + 32000]$
$= 10,79,280$ J
$= 1079280 \times 2.78 \times 10^{-7}$ kWh $= .3$ kWh

Energy i/p $= 5 \times \frac{10}{60} = .833$ kWh.

$\eta = \frac{o/p}{i/p} \times 100 = \frac{.3}{.833} = 36\%$.

Heating of Buildings:—

In cold countries like European countries, it is very essential to heat the buildings. They used to produce heat by burning fuels like wood in their houses. In all the houses there are some chimney like structures through which smoke is ~~released~~ liberated to atmosphere.

In order to have a comfortness, the normal atmosphere temp should be 27°C & inside temp in our houses should not be less than 17.2°C.

For this purpose, buildings are heated by electric heating. There are various methods of electric heating of buildings.

1) High temp. radiators. 2) Low temp. convectors.
3) Panel heating. 4) Air conditioning 5) Thermal storage.

1) High temp radiators:—

In this method, there are electric radiators in which resistance element is present. When the supply is given, these elements are heated to red hot. In this way, by keeping these radiators in houses, the surrounding atm will get heated. But the drawback is the heat is produced only at a localized region.

2) Low temp convectors :- In this method, there are metal tubes having 50mm dia, inside which res. wire And, this set up is mounted around the stirring room. Hence, the heat transfer takes place by convection to the walls & also by radiation. These elements operate at 93°C.

3) Panel heating :- In this method, there are large panels are present in which res. wire is incorporated. Such panels are mounted on the walls or ceiling of the building. This will tend to give very uniform distribution of heat & the heat is transferred through radiation.

4) Thermal storage :- In this method hot water is circulated through pipes & radiators which are fixed on the walls. The water is heated electrically.

5) Air conditioning :- In this method, the air is preheated, that means, the air is allowed to pass through the res. heater & this heated air is circulated throughout the building by ventilating equipment. This method involves cooling in summer & heating in winter. By this method humidity, purity of air as well as temp. is controlled.

Electric welding :-

[...]ing :- Welding is a process in which two metal parts joined by heating.

Welding is broadly classified into two types. i) Plastic welding (or pressure) & ii) Fusion welding (or Non-pressure).

In plastic welding, the pieces of metal to be joined are heated to a plastic state & are fused together by external pressure. It is subdivided into - i) Forge welding ii) Res. welding iii) Thermit welding. In which pressure is reqd.

In fusion welding, the two metal pieces are heated to molten state, then joined & allowed to solidify. It may be subdivided into i) Gas welding ii) Arc welding iii) Thermit welding, without external pressure.

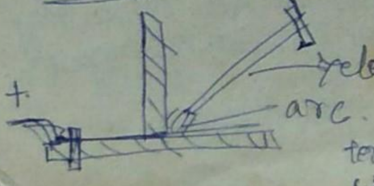
Electric welding :- Electric welding is defined as that branch of welding in which electric C^L is used to produce large amount of heat reqd for joining the two metal pieces.

Electric welding
- Res. welding
  - Butt welding
  - Flash welding
  - Spot welding
  - Projection welding
  - Seam welding
- Arc welding
  - Metal arc welding
  - Carbon arc welding
  - Atomic hydrogen arc welding
  - Helium or Argon welding

Arc welding :-

In arc welding, an electric arc is produced by bringing the two conductors in contact momentarily which are connected to a suitable source of electric C^L & then by separating them by small distance. Then the C^L continues to flow a/c a small air gap & gives intense heat. The heat developed is utilised to melt the part of work piece which are to be joined.

Principle of arc welding :- As shown in the fig. we can use AC source or DC source to produce electrode C^L. One terminal of the supply is connected to the electrode & another terminal is connected to the work piece to be welded.



When the electrode is brought nearer to the workpiece, arc will struck & then the electrode is separated by a distance. The proper gap is maintained bet^n the tip of electrode & the surface of the work piece of about 3 mm. In this case, the electrical energy is converted into heat energy of about 3000°C. This heat is utilised to join the metal pieces.

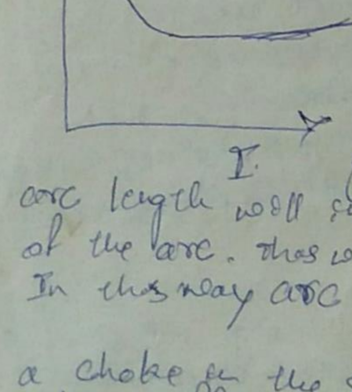
Conditions for successfull welding :-

For successful welding either AC or DC supply may be used, even though Al & certain alloys can only be welded with DC. The sparking volt. should be regularly in the range of 80 – 100 V in case of AC & 60 – 80 V in case of D.C. The arc volt. depends upon the type of the metal & the flux of the electrode. It is affected by the length of the arc being maintained, a long arc requires a higher volt. than a short arc, but a good operator will maintain correct length of arc & hence, correct arc volt. The C^n is also depending upon the type of the metal being welded & the type of the electrode & is from 15 – 600 A. for hand welding & upto 1200 A for automatic welding.

Electric properties of an Arc :-

i) Arc stability :- Electric arc has –ve res. characteristics. With the increase in the C^n, the volt. a/c the arc will decrease & as well as the res. of the arc decreases.

This is shown by the V – I char. as below.



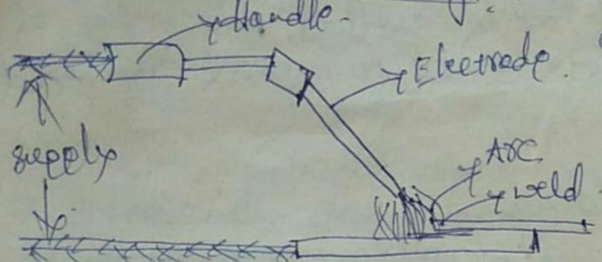
It is not possible manually to hold the arc length constant. The decrease in arc length will result in decrease in the arc res. & hence, increasing the arc C^n. This will further reduce the arc res. In this way cause & effect will go on helping each other. ||^ly increase in arc length will increase its res. This will reduce the intensity of the arc. This will result again in the increase in the res. In this way arc will extinct.

Arc stability is achieved in AC by putting a choke in the supply line. This choke will maintain constant phase difference bet^n C^n & arc volt.

Arc blow:- Arc deflection is known as arc blow
Sufficient amount of volt. is reqd to strike the arc
... DC supply.

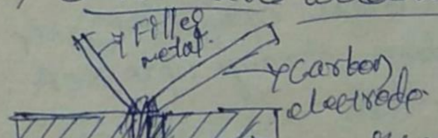
Methods of Arc welding:-

1) Metallic arc welding:-



In the metallic arc welding a metal rod is used as an electrode & the arc is struck betn the electrode & the work piece. We can use AC ~~or DC supply~~ from the sec of the welding x^r or DC from welding generator, which is connected a/c the work piece & the electrode. The electrode is allowed to touch the metal piece momentarily & then separated immediately. Hence, arc is struck betn the electrode & work piece. Due to the heat generated by the arc, a little portion of work piece melts, also the electrode. The two metal pieces to be welded are fused together & when the electrode is removed the metal cools & solidifies. Thus resulting into a strong welded joint. In this method, the arc temp is about 3500°C. More sound will be heard if the arc length is short. In order to produce soundless arc, the volt a/c the arc should be 20-25 V. The C^t flowing depends upon the type of the joint made. For eg. lap joint requires more C^t as compared to butt joint.

2) Carbon arc welding:-



This method is normally used for welding Cu & its alloys. If DC supply is used, the carbon electrode should be connected to the -ve terminal & the workpiece which is to be welded to the +ve " . Hence, more heat is produced at the work piece joint which is to be welded than at the electrode tip. If carbon electrode is connected to the +ve terminal w.r.t. workpiece, then, more heat will be produced at the tip of the electrode. Due to this, the carbon particles may mix with the metal piece & can cause brittleness. ~~For~~

For this type of welding only DC can used. When the arc is struck bet^n the electrode & the workpiece, a large amount of heat is produced which is used to melt the metal pieces. The extra metal reqd to make the weld is supplied by filler rod of the same composition as that of the ~~metal rod~~ molten metal. Two methods of carbon arc welding are used. In one method, no flux is used & in other method, flux either in the form of powder or paste is used to prevent the weld from oxidation

3) Atomic hydrogen arc welding:-

In this type of welding, ~~the arc is struck bet^n two~~ Two tungsten electrodes are connected after either AC or DC supply. The arc is struck bet^n these two tungsten electrodes. Then, the molecular hydrogen is blown through this arc. Due to the high temp developed i.e. 4000°C the hydrogen molecules changes to its atomic state. When the atomic hydrogen H_2 travels to cooler regions in the vicinity of the arc it regains its molecular form. In this process, it gives up the energy which it had received from the arc. Thus, very intense heat is generated which is used to melt the workpiece to be welded. After cooling, the two pieces will get welded. A filler rod may be used if additional metal is reqd for making the joint.

This method is used for welding stainless steel & non-ferrous metals.

To strike & maintain the arc open ckt. volt of 300V is reqd & for hand welding c^n range up to 50A is reqd.

4) Helium or argon welding or Inert gas metal arc welding:-

In this method, an arc is struck bet^n ~~electrode~~ electrode of tungsten & the metal work piece to be welded. In this case no ~~extra~~ filler rod is used since, the electrode is consumable. Large amount of heat produced is utilized to weld the work piece. In this case, ~~bet~~ helium or argon gas is blown through the arc on to the joint to give an inert atmosphere. Hence, oxidation of the welding joint does not take place.

This process of welding is used for welding of Al & its alloys, stainless steel, Cu alloys, etc. (14)

Straight & reverse polarity in DC welding:—

Types of electrodes:— i) Bare wire rods
ii) Dipped or lightly covered electrodes
iii) Heavy coated "

Resistance welding:—

In 1885 by prof. Elihu Thompson.

Resistance welding is that process in which a sufficiently strong electric C^{nt} is sent through the two metal pieces in contact to be welded which melts the metals by the res. they offer to the flow of electric C^{nt}.

Principle of res. welding is that when very high electric C^{nt} is passed through the metal pieces to be welded. Then, due to the res. offered by the metal pieces to the flow of large amount of C^{nt} large amount of heat is produced. Then, the metal pieces melt to their plastic state. The pieces are then pressed together by applying external mechanical pressure. Now, the metal pieces are said to be welded.

WKT, the heat generated, H is given by $H = I^2Rt$ where, 'R' is the total res. of the metal work pieces to be welded. This res. includes, the res. of the metal pieces which offers opposition to the flow of electric C^{nt} through it & the res. of the joint to be welded.
I - C^{nt}, t - time.

Alternating C^{nt} is found to be most suitable for the res. welding as it can provide any desired value of C^{nt} & volt. by using suitable X^{r}.

The amount of C^{nt} reqd is about 4400 to 5000 A/cm^2 of the area to be welded & the pressure reqd is 280–565 kg/cm^2.

Advantages of res. welding:—

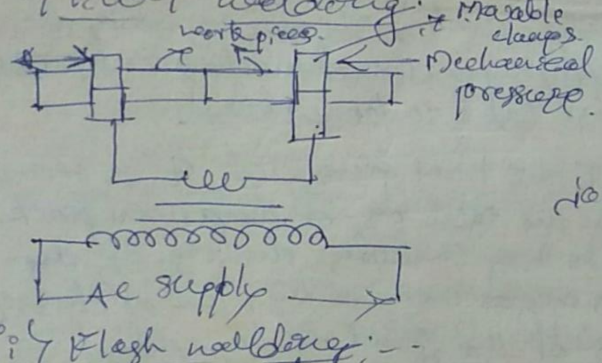
i) It is quick method of joining two pieces.
ii) There is very little wastage of metal.
iii) The process can be very accurately controlled.
iv) The welding is uniform.

Limitations:

i) Initial cost of the equipment reqd is high.
ii) In some materials, special surface preparation
iii) Skilled persons are reqd for the maintenance of the equipment & its control.

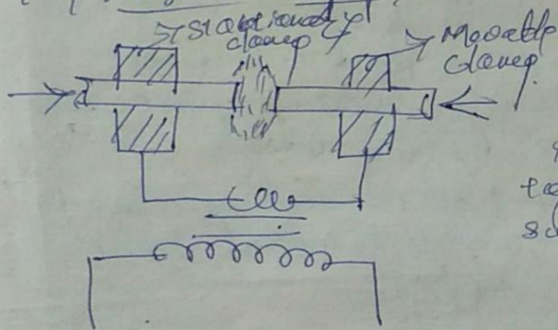
i) Butt welding
ii) Flash ,,
iii) Spot ,,
iv) Seam ,,
v) Projection ,,

i) Butt welding:



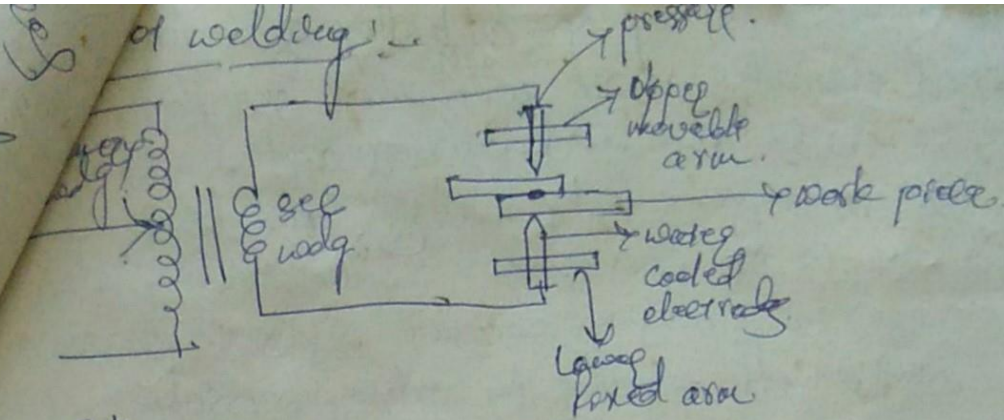
Applications:
i) For welding pipes, wire & rods.
ii) Where the pieces are joined end to end or edge to edge.

ii) Flash welding:—



Applications:-
This method is of welding is used in production work, in welding rods & pipes together. This method is superseded over butt weld method.

Sp[illegible] of welding :-



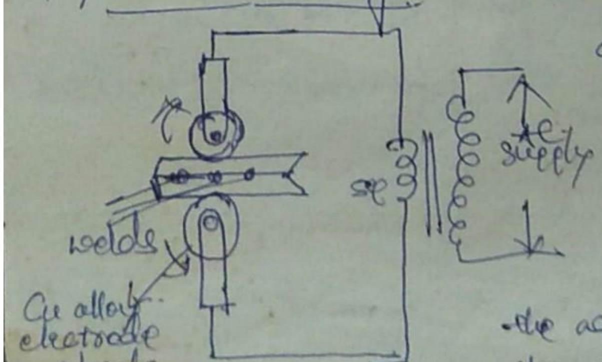
C^L 5000 A.
Volt bet^n electrodes < 3V
" " o.c. < 12V.

This is the simplest & most universally adopted method of making laps welds in thin sheets. In its simplest form the spot welding m/c consists of a X^r, the electrodes & the electrical control switch.

In the process, the materials to be welded are overlapped & pressed bet^n two water cooled electrodes & a impulse of C^L is passed through the assembly. The metals in the zone of pressure gets heated up to fusion & joint thus made gets cooled under pressure. For spot welding 5000A of C^L is reqd. & volt. bet^n electrodes is usually less than 3V. The open ckt volt. is less than 12V. The quality of spot welding depends upon the value of welding C^L, the time for which the C^L flows & the pressure bet^n the electrode tips.

Applications :- i) It is applied to welding of sheets.
ii) It may be applied to all types of boxes, cases & enclosing cases, etc.

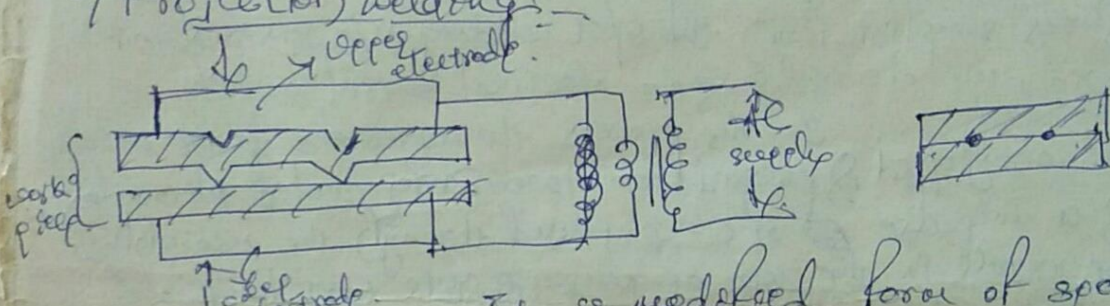
iii) Seam Welding :-



Seam welding can be defined as series of continuous spot welding. This process is employed for making a continuous joint bet^n two overlapping pieces of sheet metal. In this process the work to be welded is placed bet^n electrode & are made up of Cu alloy & are water cooled. These wheel electrodes carry sufficient Cⁿ for producing continuous welds. The mech. pressure applied is kept constant & Cⁿ is regulated by timer. The heat is generated due to the flow of Cⁿ in the welding ckt. Here, the metal pieces in contact melts to plastic state they are joined together by applying pressure.

Applications :- i) It is used for making lap & butt welds
ii) It is quicker than spot welding operation.
iii) It is used on many types of pressure tight or leak proof tanks for various purposes.

v) Projection welding :-



It is modified form of spot welding. ~~Project~~ In this method slight projections are made on one work piece. The edges of the projections are kept on the other work piece at the portion where it is to be welded. The work pieces are clamped with two flat electrodes. Then if the heavy Cⁿ is allowed to flow through the work piece, then large amount of heat is produced ~~at the~~ due to the res offered to the flow of Cⁿ. Hence, the projected contact area melts to plastic state then if the mechanical pressure is applied it forms a strong welded joint at the points.

Projection welding has certain advantages over spot welding :-
i) More than one spot welding is done at a time.
ii) Due to the low Cⁿ density & low pressure the electrode life is increased.
iii) Good finished appearance is obtained, i.e. the surface remains flat.

Electrolytic Process

Fundamental Principles

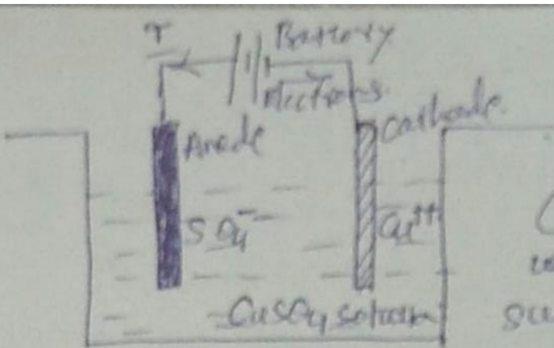
~~Introduction~~

The Processes in which electrical energy is used to produce chemical changes are called electrolytic processes, which are used for the following purposes.

i) Extraction of pure metals like copper, zinc, aluminium, magnesium, etc from their ores.
ii) Refining of metals such as gold, silver, copper, nickel etc.
iii) Manufacturing of various chemicals such as castic soda, potassium permanganate, chlorine, etc.
iv). Electro-plating, electro-typing, electro-forming, etc
v). Building up of worn parts in chemical, metallurgical & other industries

Electrolysis :-

An electrolyte is a chemical compound, whose molecules are closely bound together in its normal state. But, when it is dissolved in water & forms a solution, the molecules split-up into two types of ions, +Ve ions & -Ve ions. And, freely move about in the solution. If two electrodes are dipped into the electrolytic solution and connected to a DC source, +Ve ions move towards the cathode & the -Ve ions move towards the anode.



Let us take the example. When copper sulphate ($CuSO_4$) is dissolved in water, it becomes copper sulphate solution.

The solution dissociates itself into +Vely charged copper ions (Cu^{++}) & -Vely charged sulph ions (SO_4^{--}) moving freely in the solution.

If two electrodes are dipped in the electrolyte as shown above, & connected to a battery, the +Vely charged copper ions (Cu^{++}) move towards the cathode & the -Vely charged sulph ions (SO_4^{--}) move towards the anode. Each of the +Vely charged copper ions, on reaching the cathode, take two electrons from it & becomes a metallic atom of copper & gets itself deposited on the cathode in a very pure form. |||ly, the -Vely charged sulph ions, on reaching the anode, will give up two electrons to it & become a sulfate molecule. The sulfate molecules at the anode react with water liberating oxygen.

$$2SO_4 + 2H_2O = 2H_2SO_4 + O_2 \rightarrow (1)$$

In addition to oxygen, sulphuric acid is also formed at the cathode. If the anode is made of copper, the sulphuric acid attacks the anode forming copper sulphate & liberating hydrogen.

$$H_2SO_4 + Cu = CuSO_4 + H_2 \rightarrow (2)$$

Hence, during the entire process, copper from anode gets itself deposited on cathode in its pure form & there is no accumulation of charges at any point of time. The entire process described above is known as electrolysis.

Faraday's laws of electrolysis

First Law:- The mass of substance liberated during electrolysis is directly proportional to quantity of electricity flowing through the electrolyte.

$m \propto Q \propto It$

$\Rightarrow m = ZIt \rightarrow (3)$

where, m - mass of substance liberated in kg.

Z - a constant known as the electro-chemical equivalent of the substance in kg/C.

I - Current flowing in amperes

t - time for which current flows in sec.

From eqn (3),

$Z = m$, if $I = 1A$ & $t = 1$ sec.

∴ The electrochemical equivalent Z of a substance is defined as the amount of the substance deposited, when a current of 1A flows through the electrolyte for 1 sec.

The unit of Z is kg per coulomb i.e, kg/C

Second Law:- When the same quantity of electricity is passed through several electrolytes, the masses of the substances liberated are proportional to their respective chemical equivalents or equivalent weights.

$$\text{Chemical equivalent} = \text{Equivalent weight} = \frac{\text{Atomic weight}}{\text{Valency}}$$

Current Efficiency:

During the process of electrolysis, the quantity of the substance deposited is slightly less than the quantity calculated by Faraday's laws because of the impurities present, which results in secondary reactions. This factor is taken into account by defining current efficiency.

The current efficiency is defined as the ratio of the actual quantity of the substance deposited to the theoretical quantity of the substance deposited as calculated from Faraday's laws.

$$\text{Current efficiency} = \frac{\text{Actual quantity of the substance deposited}}{\text{Theoretical quantity of the substance liberated}}$$

In most of the cases, this value lies bet— 90 – 98%.

Energy Efficiency

Due to the secondary reaction, the actual quantity of the substance deposited is less than the quantity as determined theoretically from Faraday's laws. The actual voltage reqd for depositing a certain quantity of the substance is also more than the theoretical value. Hence, the actual energy consumption is always more than the theoretical value for depositing a certain quantity of the substance. This factor is taken into account by defining energy efficiency.

The energy efficiency is defined as the theoretical energy required for depositing a certain quantity of the substance to the actual value of the energy reqd.

$$\text{Energy efficiency} = \frac{\text{Theoretical energy reqd}}{\text{Actual energy reqd}}$$

Electrode Potential

The voltage applied to an electrolytic cell is equal to the sum of the voltage drops due to the resistance of the electrodes and the res. of the electrolyte. For the electrolytic process to be more efficient, the res. of the electrolyte must be as small as possible. For achieving this, special conducting agents are added to the electrolyte. For eg. Sulphuric acid is added as a conducting agent to copper sulphate solⁿ in copper plating. A P.d. exists betⁿ the anode & the electrolyte & also betⁿ the cathode & the electrolyte. This p.d. is known as the electrode potential & is a measure of the tendency of the metal to go into the solution. The electrode potential depends on the temp. & concentration of the electrolyte. For most of the metal deposition processes, the electrode potential is of the order of .5 to 1.0 V., whereas the total voltage reqd to pass the necessary cᵗ through the electrolyte is of the order of 10 or 20.

Extraction of metals

Extraction of metals is an electrolytic process in which a metal with commercially acceptable purity can be obtained. There are two different methods of extracting the metal depending on the physical state of the ore.

i) In one of the methods, the ore is treated with a strong acid to obtain a salt of the metal & treated with a strong acid. When the solution of the salt is electrolysed, the metal is liberated.