Heat Transfer

Types of Heat transfer :-

There are three types of heat transfer such as :-

(i) conduction

(ii) convection

(iii) Radiation

(i) Conduction :-

- Conduction is the process of heat transfer, which transfer heat from one molecule of the body to another molecule, without actual motion of the body.
- Heat transfer by solid medium.
- Ex :- Iron rod is heated by one end.

(ii) Convection :-

- Convection is the process of heat transfer, from which heat transfer from one particle of fluid to another particle by the actual motion of the heated particle.
- Heat transfer by liquid medium.
- Ex :- Boiling of water.

(iii) Radiation :-

- Radiation is the process of heat transfer from a hot body to a cold body in a straight line without affecting in the intervening medium.
- Heat transfer by vaccum or gaseous medium.
- Ex :- Heat from the sun reaches to the earth.

* **Alloy:-**
  - It is a mixture of two or more metals.
  - It's melting point between a range.
* **Pure metal:-**
  - It is melt at one point.
* **Black Body:-**
  - Black body one which neither reflects nor transmits any part of the incident radiation but absorb all the radiation.

  Properties:-
  - It absorbs all the incident radiation.
  - It does not transmit or reflect the wavelength and deviation.
  - It emits maximum amount of thermal radiation at all wavelength at any specified temperature.
* **White Body:-**
  - If all the incident radiation falling on the body are reflected, it is called "white body".
* **Steel:-** 1400°c - 1450°c (melting point)
* **Flow:-** Higher level to lower level
* Good **conductor:-** Allows heat and electricity to pass.
* Bad **conductor:-** Doesn't allow heat and electricity to pass

  Water Boiling point = 100°c, freezing point = 0°c

  Pure metal → One metal in pure form.

* Regular reflection:-

The angle between the reflected beam and the normal to the surface equals the angle made by the incident radiation with the same normal. Polish surface given regular reflection.

Diffused reflection:-

- The incident beam is reflected in all direction.
- Rough surface given diffused reflection.

* Grey Body:-

- It is a body, whose absorptivity of a surface does not vary with temp & wavelength of the incident radiation.

* Emissivity:-

- The amount of heat released by the body.

* Fluid:-

- Ability /tends to flow.
- Flow from higher level to lower level.

* Velocity:-

- Resistance to deformation at a given rate.

Types of fluid :-

(i) IDEAL FLUID :-

- If the fluid can not be compressed and viscocity does not fall then the fluid said to be 'ideal fluid'.

- It is a imaginary fluid, which doesnot exist in reality.

(ii) REAL FLUID :-

- If the fluid can be compressed and pose viscocity then that fluid said to be "real fluid".

(iii) NEWTONIOUS FLUID :-

- The fluid which obey Newton's law of viscosity is known as "Newtonian fluid".

Newton's law of Viscocity :-

- Shear stress is directly proportional to velocity gradient.

Velocity Gradient :-

- Difference in velocity of different layer of liquid.

Shear stress :-

- Stress that applied parallel or tangential to the force applied, is known as shear ~~to~~ stress.

(v) Ideal plastic fluid :-

When the shear stress is proportional to the velocity gradient and shear stress is called Ideal plastic fluid.

(vi) In compressible fluid :-

When the density of fluid doesn't change with application of external force.

(vii) Compressible fluid :-

When the density of a fluid change with the application of external force.

Friction :- Resisting force which approx the motion.

Non-viscosious :- Friction force between that layer of water will be zero.

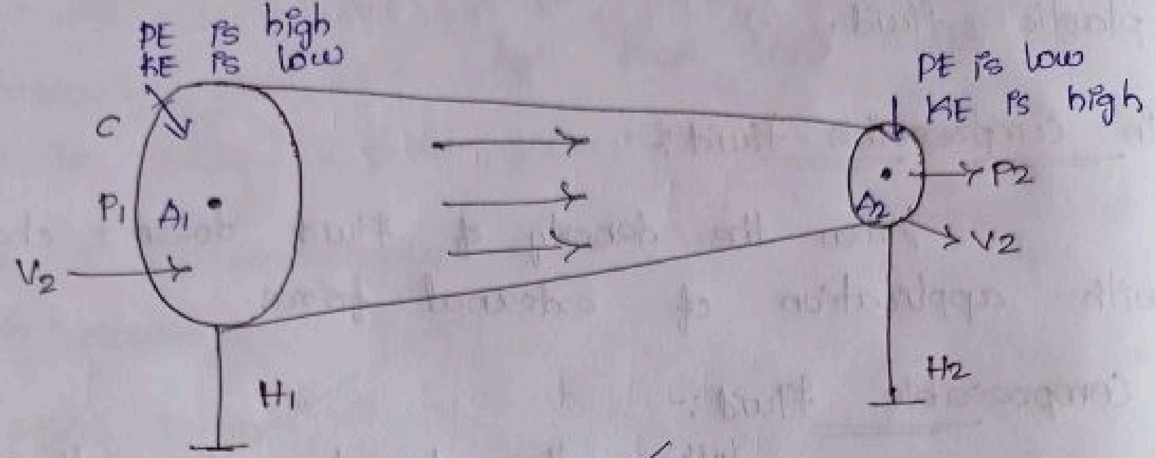
~~In compressible :- liquid which cannot be compress~~

~~Steamline flow :- liquid particle flow in compress~~

Frictional free flow :- Water layer flow.

(iv) Non - Newtonious fluid :- Doesn't obey Newton's law of viscocity.

Bernoullis Equation :-



V - Velocity

P - Pressure

H - Height

1 - Potential energy - Mgh (constant)

2 - Kinetic energy - $\frac{1}{2}MV^2$ (moved)

3 - Pressure energy

Kinetic energy

$$\frac{1}{2}MV^2 = \frac{1}{2}MV_2^2 - \frac{1}{2}V_1^2 \quad \text{(1)}$$

[D.C]

(Total kinetic energy = KE at point P $= \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$ c)

→ Kinetic energy is high because velocity is high.

Potential energy

Total Potential energy

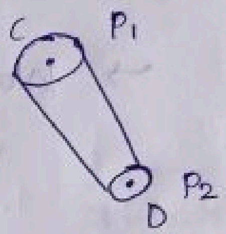
$mgh = mgh_1 - mgh_2$

→ PE energy is at point C

$mgh_1 - mgh_2$ D ⟶ ②

Work Done

Work = force × Displacement



$$\text{Pressure} = \frac{\text{force}}{\text{Area}}$$

⟹ $F = P \times A$

⟹ $(P \times A)(V \times T)$

$A \times V \times t = \text{Volume}$

$$\text{Volume} = \frac{\text{mass}}{\text{density}}$$

(or)

$$\text{Vol} \ \frac{\text{mass}}{\text{density}}$$

{ Displacement
Shortest Distance

$$P = \frac{F}{A}$$

$$\text{Pressure} = \frac{\text{Force}}{\text{unit Area}}$$

⟹ $F = P \times A$

$$\text{Volume} = \frac{\text{mass}}{\text{density}}$$

Work done at C

$$P \ \frac{\text{mass}}{\text{density}}$$

$$PV = \frac{\text{mass}}{\text{density}}$$

$$P \times \frac{\text{mass}}{\text{density}}$$

Work done

$$WD = \text{force} \times \text{Displacement}$$

$$= (PA)(vt)$$

$$= PAVT$$

→ Volume $= \frac{mass}{density}$

$$= P \times \frac{m}{D}$$

→ Work done at Point C

at point D

C D

$$= P_1 \frac{m}{d} - P_2 \frac{m}{d} \longrightarrow (3)$$

eq^n (1) + (2) + (3) Add = conservation law of energy

Increase in KE = Decrease in PE + W.D

$$\Rightarrow \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2 = mgh_1 - mgh_2 + P_1\frac{m}{d} - P_2\frac{m}{d}$$

$$\Rightarrow \frac{1}{2}mv_2^2 + mgh_2 + P_2\frac{m}{d} = +\frac{1}{2}mv_1^2 + mgh_1 + P_1\frac{m}{d}$$

LHS RHS

$$\Rightarrow \frac{1}{2}mv_2^2 + mgh_2 + P_2\frac{m}{d} = \frac{1}{2}mv$$

$$\Rightarrow \frac{d}{m} = \frac{1}{2}mv_2^2 + mgh_2 + P_2\frac{m}{d}$$

$$\Rightarrow \frac{d}{m} \times \frac{1}{2}mv_2^2 + \frac{d}{m}mgh_2 + \frac{d}{m}P_2\frac{m}{d}$$

$$\Rightarrow \frac{dv_2^2}{2} + dgh_2 + P_2$$

$\Rightarrow \frac{v_2^2 d}{2} + gh_2 d + P_2$ (constant)

$\Rightarrow \frac{v_1^2 d}{2} + gh_1 d + P_1 =$ (constant)

LHS = RHS

Reynold's no :-

→ In the case of pipe flow. The linear dimension of taken 'L' is the diameter. Hence reynold's no for the pipe flow

$$Re = \frac{v \times d}{\eta} = \frac{\frac{v \times d}{\mu}}{\rho}$$

ρ = rao
μ = miu
η = eta

$$Re = \frac{v \times d \times \rho}{\mu}$$

$\eta = \frac{\mu}{\rho}$

$\eta = \frac{\text{miu}}{\text{Row}}$

η = Linear velocity
v = Velocity
μ = Viscosity
ρ = Density

Newton law of viscosity

Mathematically

$$\tau \propto \frac{du}{dy} \Rightarrow \tau = \mu \frac{du}{dy}$$ water range

μ = constant of proportionality or coefficient of dynamic viscosity

$\frac{du}{dy}$ = Velocity gradient
or
Shear stress.

Types of Flow :-

1. Streamline Flow :-

It is defined as the type of flow in which the fluid particle move along well defined path or streamline and all the streamline are straight and parallel. the particles move in layers glinding smoothly over the adjacent layer.

→ If the reynold's no is less than 2000 the flow is lamminer.

2. Turbulent :-

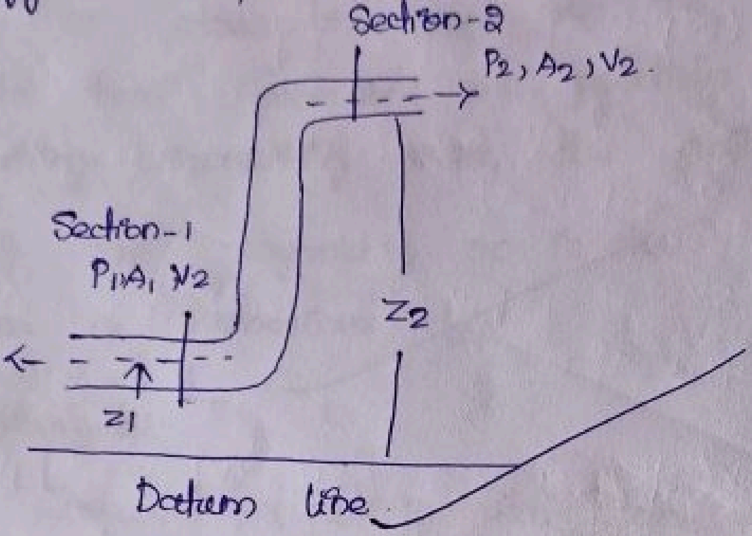
Turbulent flow is that type of flow in which the fluid particles move zig - zag way. If reynold's no is more than 4000 the flow is called turbulent flow.

3. Mixed Flow :-

It is Reynold's no lies between 4000 the flow is called mixed flow.

Bernoullis Equation :-

It states that in a steady, ideal flow of an incompressible fluid. The total energy at any point at the fluid constant. The total energy, kinematic energy and potential energy.



→ Consider a flow of a incompressable fluid through a pipe of varying cross-section.

→ Take two section 1 & 2 let A_1 = cross-section area at section-1

A_2 = cross section area at section 2

P_1 & P_2 = Pressure in section 1 → Pressure in section 2

V_1 = velocity at section 1

V_2 = velocity at section 2

Z_1 = Height of the centre of the pipe at section-1 is from ground level or datumline.

A_2, P_2, V_2 and z_2 are the corresponding values at section - 2.

Determination of pressure Energy :-

The pressure energy input at section - 2 is $P_1 A_1 V_1$

The pressure energy output at section - 2 is $P_2 A_2 V_2$

Inlet pressure energy stored in the fluid between two section is

$$E_{pressure} = P_1 A_1 V_1 - P_2 A_2 V_2 \longrightarrow (1)$$

Determination of Kinetic energy :-

The Kinetic energy input at section - 1 is

$$\frac{1}{2} m v^2 = \frac{1}{2} \rho A_1 V_1 \times V_1^2 = \frac{1}{2} \rho A_1 V_1^3$$

The Kinetic energy output at section - 2 is

$$= \frac{1}{2} \rho A_2 V_2^3$$

The inlet Kinetic energy stored in the fluid in between two sections is

$$E_{KE} = \frac{1}{2} \rho A_1 V_1^3 - \frac{1}{2} \rho A_2 V_2^3 \longrightarrow (2)$$

Determination of ~~Kinetic~~ Potential energy :-

The potential energy at section - 1 input is

$$\rho A_1 V_1 \times g \times z_1 = \rho A_1 V_1 g z_1$$

The potential energy output at section - 2 is

$$\rho A_2 V_2 \times g \times z_2 = \rho A_2 V_2 g z_2$$

Inlet potential energy stored in between two section $E_p = \rho A_1 V_1 g z_1 - \rho A_2 V_2 g z_2 \longrightarrow (3)$

According to Bernoulli's theorem

Total energy = constant

Σ pressure +KE +PE = 0

from the equation ①, ② and ③ we get

$\Rightarrow (P_1A_1V_1 - P_2A_2V_2) + (\frac{1}{2}\rho A_1 v_1^3 - \frac{1}{2}\rho A_2 v_2^3) + [\rho A_1 v_1 g z_1 - \rho A_2 v_2 g z_2] = 0$

$\Rightarrow P_1A_1V_1 - P_2A_2V_2 + \frac{1}{2}\rho A_1 v_1^3 - \frac{1}{2}\rho A_2 v_2^3 + \rho A_1 v_1 g z_1 - \rho A_2 v_2 g z_2 = 0$

$\Rightarrow P_1A_1v_1 + \frac{1}{2}\rho A_1 v_1^3 + \rho A_1 v_1 g z_1 = P_2A_2V_2 + \frac{1}{2}\rho A_2 v_2^3 + \rho A_2 v_2 g z_2$

$\Rightarrow A_1v_1(P_1 + \frac{1}{2}\rho v_1^2 + \rho g z_1) = A_2v_2(P_2 + \frac{1}{2}\rho v_2^2 + \rho g z_2)$

According to equation of continuity

$A_1V_1 = A_2V_2$

Hence the above equation is reduced to

$P_1 + \frac{1}{2}\rho v_1^2 + \rho g z_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g z_2$

Dividing both sides by ρg, then we get

$\frac{P_1}{\rho g} + \frac{1}{2}\frac{\rho v_1^2}{\rho g} + \frac{\rho g z_1}{\rho g} = \frac{P_2}{\rho g} + \frac{1}{2}\frac{\rho v_2^2}{\rho g} + \frac{\rho g z_2}{\rho g}$

$\Rightarrow \frac{P_1}{\rho g} + \frac{1}{2}\frac{v_1^2}{g} + z_1 = \frac{P_2}{\rho g} + \frac{1}{2}\frac{v_2^2}{g} + z_2$

(or)

$\frac{P_1}{\rho} + \frac{1}{2}v_1^2 + g z_1 = \frac{P_2}{\rho} + \frac{1}{2}v_2^2 + g z_2$

This represent Bernoulli's equation of two section.
This equation can be written as

$$\frac{p}{\rho g} + 1/2 \frac{v^2}{g} + z = \text{constant}$$

(or,)

$$\frac{p}{\rho} + 1/2\, v^2 + z = \text{constant} \rightarrow (1)$$

Euler's equation:-

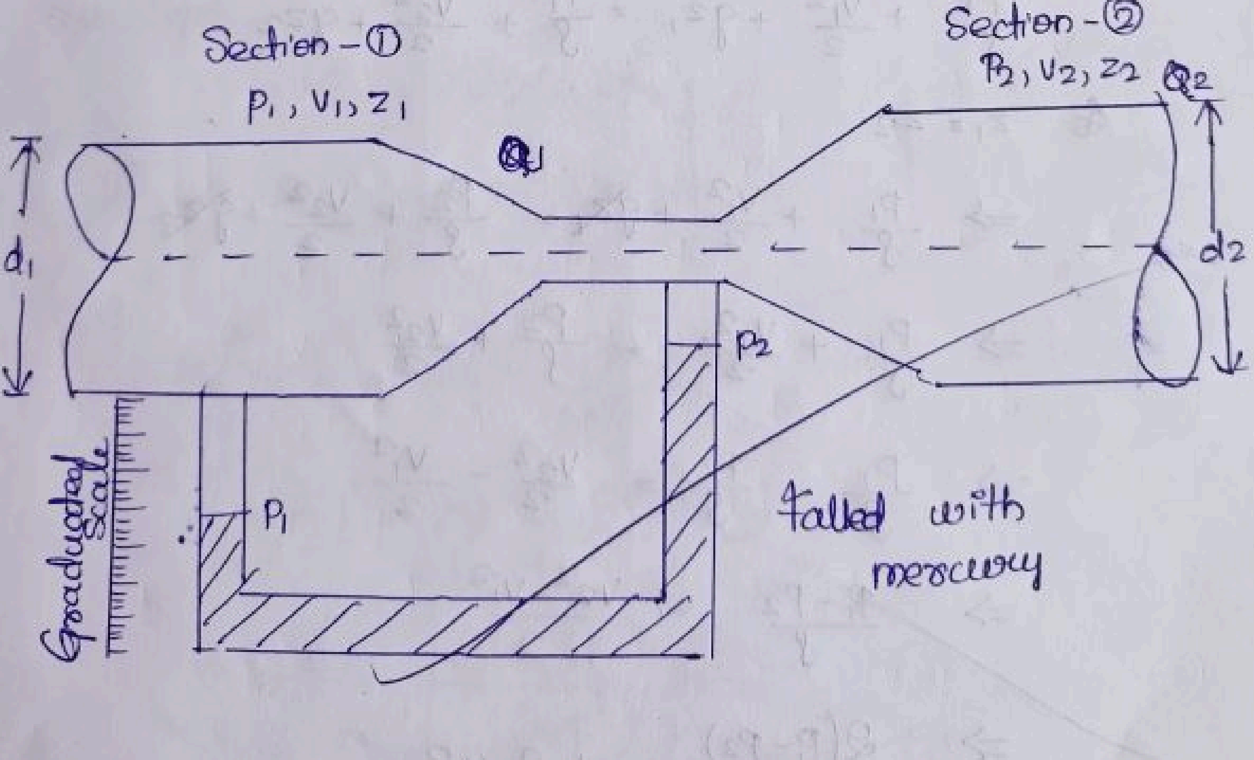
By differentiating equation -(1) above we get,

$$\frac{dp}{\rho} + dv + g dz = 0$$

This differential form of energy equation is known as euler's equation of motion along a stream line fluid flow.

The flow through orifices, pilot tube and ventury tube (meter): Flow through ventury meter

$Q_1 = Q_2$



Venturi meter is a device used for measuring volumetric flow rate of a fluid through a pipe. It consists of three parts. They are;

(a) Throat

(b) Converging part

(c) Diverging part

A U-tube manometer is effect in between the tube to measure of pressure head.

Let d_1 = diameter of section → ①

p_1 = pressure

v_1 = velocity

a_1 = Area of section ① $\pi/4 \, d_1^2$

Similarly d_2, p_2, v_2 and a_2 are the corresponding values at section - ②

Applying Bernoulli's equation we get

$$\frac{p_1}{\rho} + \frac{V_1^2}{2} + gz_1 = \frac{p_1}{\rho} + \frac{V_2^2}{2} + gz_2$$

As $z_1 = z_2$

$$\Rightarrow \frac{p_1}{\rho} + \frac{V_1^2}{2} + gz_1 = \frac{p_2}{\rho} + \frac{V_2^2}{2} + gz_2$$

$$\Rightarrow \frac{p_1}{\rho} + \frac{V_1^2}{2} = \frac{p_2}{\rho} + \frac{V_2^2}{2}$$

$$\Rightarrow \frac{p_1}{\rho} - \frac{p_2}{\rho} = \frac{V_2^2}{2} - \frac{V_1^2}{2}$$

$$\Rightarrow \frac{p_1 - p_2}{\rho} = \frac{V_2^2 - V_1^2}{2}$$

$$\Rightarrow \frac{2(p_1 - p_2)}{\rho} = V_2^2 - V_1^2$$

$\Rightarrow v_2^2 - v_1^2 = \frac{2(P_1 - P_2)}{\rho} \longrightarrow ①$

Applying continuity equation

$Q = A_1 V_1 = A_2 V_2$

$\Rightarrow \pi/4\, d_1^2 v_1 = \pi/4\, d_2^2 v_2$

$\Rightarrow v_1 = \frac{\pi/4\, d_2^2 v_2}{\pi/4\, d_1^2}$

$\Rightarrow v_1 = \frac{d_2^2}{d_1^2} v_2$

$\Rightarrow v_1 = \left(\frac{d_2}{d_1}\right)^2 v_2$

Then the above eq^n becomes

$\left\{ \frac{d_2}{d_1} = \beta \right.$

$v_1 = \beta^2 \times v_2$

$v_1 = v_2 \beta^2$

Now putting the value of v_1 in equation ① we get,

$\{ v_1^2 = \beta$

$v_2^2 - v_1^2 = 2(P_1 - P_2)$

$\Rightarrow v_2^2 - (v_2 \beta^2)^2 = \frac{2(P_1 - P_2)}{\rho}$

$\Rightarrow v_2^2 - v_2^2 \beta^4 = \frac{2(P_1 - P_2)}{\rho}$

$\Rightarrow v_2^2 (1 - \beta^4) = \frac{2(P_1 - P_2)}{\rho}$

$\Rightarrow v_2^2 = \frac{2(P_1 - P_2)}{\rho(1 - \beta^4)}$

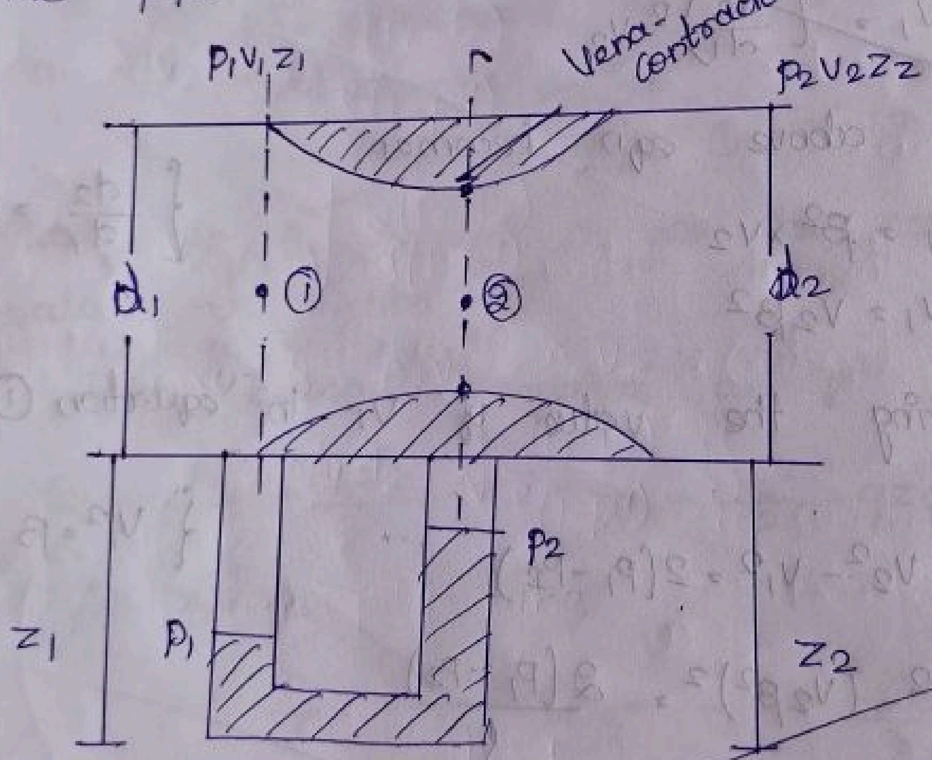
$\Rightarrow V_2 = \sqrt{\dfrac{2(P_1-P_2)}{\rho(1-\beta^4)}}$

So Now $Q = A_1V_1 = A_2V_2$

$$V_2 = \pi/4\, d_2^2 \times \sqrt{\dfrac{2(P_1-P_2)}{\rho(1-\beta^4)}}$$

Flow through orifice meter

orifice meter is a thin circular plate with a centrally located circular hole introduced into the pipe to measure the flow rate.



A u-tube manometer is fitted in the orifice to measure of pressure head

d_1 = diameter of the section ①

P_1 = Pressure at the section

V_1 = velocity at the section

a_1 = area of the section.

z_1 = distance from the ground to the section -①

Similarly d_2, P_2, V_2, a_2 and z_2 are the corresponding value at section -②

Now applying Bernoulli's equation we get,

$$\Rightarrow \frac{P_1}{\rho} + \frac{V_1^2}{2} + g z_1 = \frac{P_2}{\rho} + \frac{V_2^2}{2} + g z_2 \qquad (z_1 = z_2)$$

As $z_1 = z_2$

$$\Rightarrow \frac{P_1}{\rho} + \frac{V_1^2}{2} = \frac{P_2}{\rho} + \frac{V_2^2}{2}$$

$$\Rightarrow \frac{P_1}{\rho} - \frac{P_2}{\rho} = \frac{V_2^2}{2} - \frac{V_1^2}{2}$$

$$\Rightarrow \frac{P_1 - P_2}{\rho} = \frac{V_2^2 - V_1^2}{2}$$

$$\Rightarrow \frac{2(P_1 - P_2)}{\rho} = V_2^2 - V_1^2$$

$$\Rightarrow (V_2^2 - V_1^2) = \frac{2(P_1 - P_2)}{\rho} \rightarrow ①$$

As per the equation of continuty.

$$A_1 V_1 = A_2 V_2$$

$$V_1 \pi/4 d_1^2 = V_2 \pi/4 d_2^2$$

$$\Rightarrow V_1 = \frac{\pi/4 d_2^2}{\pi/4 d_1^2} V_2$$

$$\Rightarrow V_1 = \frac{d_2^2}{d_1^2} V_2$$

$$\Rightarrow V_1 = \left(\frac{d_2}{d_1}\right)^2 V_2$$

replace $\frac{d_2}{d_1}$ in β

$$\Rightarrow \text{If } \frac{d_2}{d_1} = \beta$$

Then the equation becomes

$$V_1 = V_2 \beta^2$$

Now putting the value of V_1 in eqⁿ (1)

$$\Rightarrow V_2^2 - (V_2\beta^2)^2 = \frac{2(P_1 - P_2)}{\rho}$$

$$\Rightarrow V_2^2 - V_2^2\beta^4 = \frac{2(P_1 - P_2)}{\rho}$$

$$\Rightarrow V_2^2(1-\beta^4) = \frac{2(P_1 - P_2)}{\rho}$$

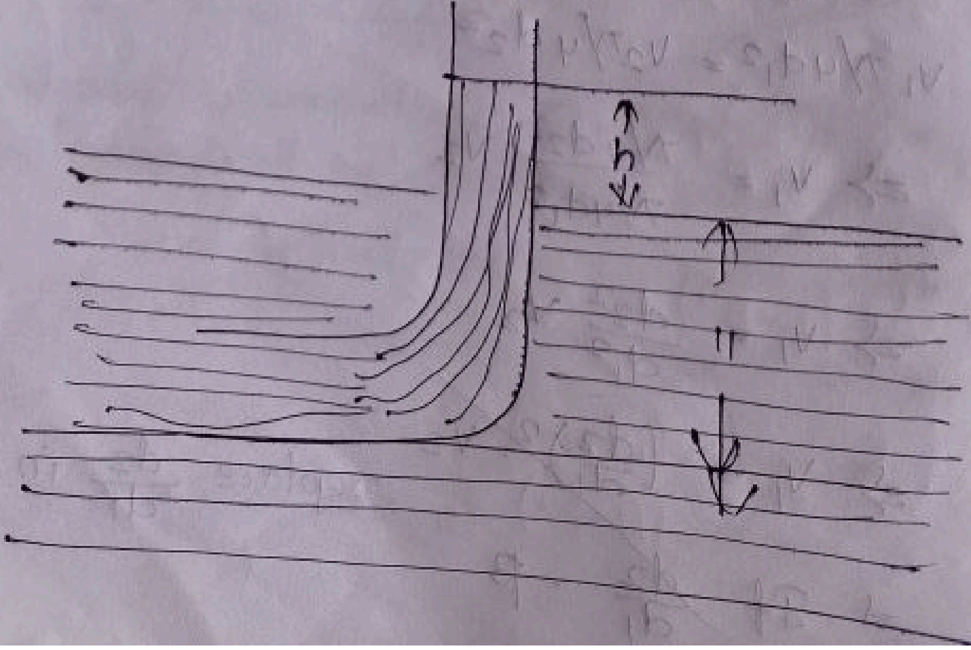
$$\Rightarrow V_2^2 = \frac{2(P_1 - P_2)}{\rho(1-\beta^4)}$$

$$\Rightarrow V_2 = \sqrt{\frac{2(P_1 - P_2)}{\rho(1-\beta^4)}}$$

So now $Q = A_1V_1 = A_2V_2$

$$V_2 = \pi/4\, d_2^2 \sqrt{\frac{2(P_1 - P_2)}{\rho(1-\beta^4)}}$$

Flow through pilot tube



pitot tube is a device used for measuring the velocity of flow at any point in a pipe or a channel. The pitot tube consists of a glass tube bent at a right angle. The lower end of the tube is directed in the stream direction the liquid rises up in the tube due to conversion of kinetic energy into pressure energy. The velocity is measured by measuring the rise of liquid in the tube

Actual velocity (v) = $C_v \sqrt{2gh}$

C_v is the coefficient of the pitot tube.

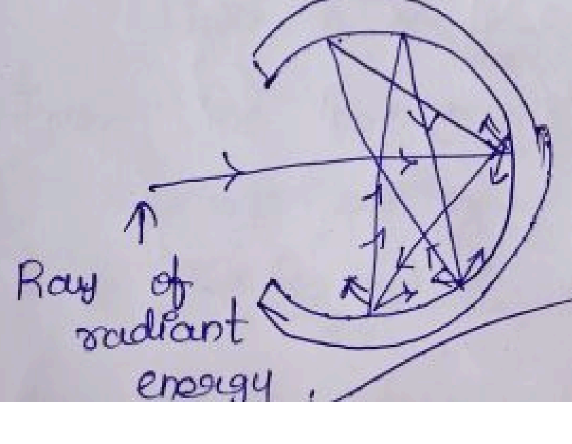
* Black Body :-

Black body one which neither reflect nor transmits any part of the incident reduction but absorb all of it.

Properties :-

→ It absorbs all the incident radiation falling on it & doesnot transmit or reflect regardless of wavelength and direction.

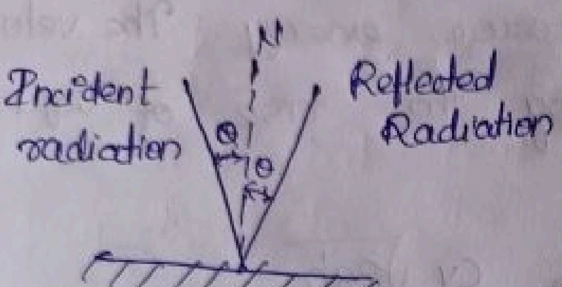
→ It emits maximum amount of thermal radiation at all wavelength at any specified temp.



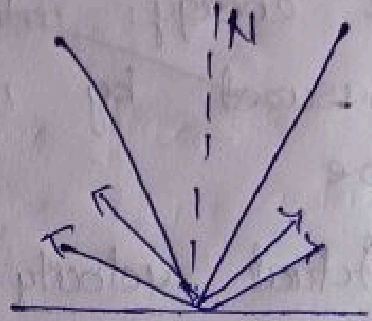
White body :-

→ If all the incident radiation falling on the body are reflected, it is called 'white body'.

Reflection are of two types



Regular reflection.



diffuse reflection.

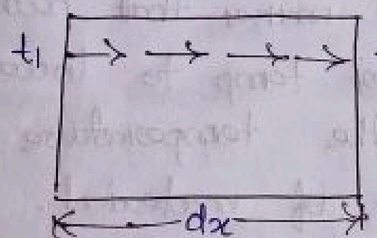
2nd Chapter

Fourier's law of Conduction of Heat :-

The law states that the rate of heat transfer flux is directly proportional to the negative temperature gradient.

Derivation

Generally in conduction process rate of heat transfer is directly proportional to the temperature difference between hot and cold point and also directly proportional to the direction of flow but inversely proportional to the distance between hot and cold point.



let Q = Rate of heat transfer (speed)

$dt = t_1 - t_2$ = Temperature difference between hot and cold point

dx = Thickness of material

A = Area of the material through which heat exchange occurs

According to Fourier's law $Q \propto A(t_1 - t_2) \times \frac{1}{dx}$

Firstly $Q \propto A \rightarrow (1)$ Area

Next $Q \propto (t_1 - t_2) \rightarrow (2)$ Temp. difference

Next $Q \propto \frac{1}{dx} \rightarrow (3)$ distance.

From the eq^n (1), (2) and (3) we get the Fourier's law as

$$Q \propto -\frac{A(t_2 - t_1)}{dx} \Rightarrow Q = \frac{-KA(t_2 - t_1)}{dx}$$

where K = Thermal conductivity of the medium

$$\Rightarrow \frac{Q}{A} = -K \cdot \frac{(t_2 - t_1)}{dx} \quad (1)$$

Here Q/A represent rate of heat transfer flux (q)

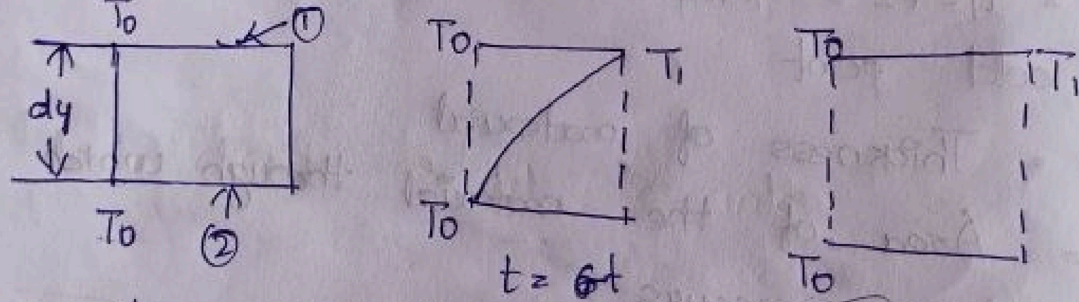
$$\Rightarrow q = \frac{-K(t_2 - t_1)}{dx} \quad (2)$$

$$\Rightarrow q \propto -\frac{dt}{dx} \quad (3)$$

This show that heat transfer flux is directly proportional to the negative temperature gradient.

The negative sign makes that heat transfer takes place from higher temp to lower temp. It also indicates that the temperature decreases with increasing thickness of material.

<u>Derivation</u> of <u>fourier's</u> <u>law</u> from <u>1st</u> principle



$t = 0$ (fig - 1)

$t = \delta t$ fig - II

$t = t_1$ (fig - III)

① Consider two plate ① and ② initially in fig - 2, both the surfaces are at temperature.

(T_0), hence there is no temperature gradient. The temperature distribution is as show in the figure - 2.

② Suddenly the upper surface is heated to a temperature (T_1) while the lower is at (T_1) for $t = 0$ + the temperature distribution over 'dy' is as shown in figure - 2.

③ for $t_2 = t_1$, where sufficient time has been allowed, steady state heat flow condition is reached, where a constant amount of heat flow between the surface ① and ② under such condition the temperature profile over 'dy' become is straight line.

It is found $(T_1 - T_0)$ is small, q_y is proportional to $(T_1 T_0)$ and inversely proportional to the distance 'y' between the surfaces.

$$q_y \propto T_1 - T_0$$

$$\propto 1/y$$

$$q_y = \frac{k(T_1 - T_0)}{y}$$

This relationship is fourier's law under differential condition in three dimensional heat flow.

$$q_y = -k\frac{dT}{dy}$$

$$q_x = -K\frac{dT}{dx}$$

$$q_z = -K\frac{dT}{dz}$$

so total heat flow in three dimensional is

$$Q = q_x + q_y + q_z$$

$$Q = -K\left(\frac{dT}{dx} + \frac{dT}{dy} + \frac{dT}{dz}\right)$$

units of q

$q = cal/sec.\,cm^2$

Units of Q

$Q = q.A$ cal/sec.

Thermal conductivity

It is defined as the quantity of heat conducted in unit time across unit area through unit thickness when a negative temperature gradient of 1°c is maintained across opposite faces.

units

In C.G.S $\longrightarrow$ cal /sec. cm°c

In S.I $\longrightarrow$ Joule /m. sec°K.

Thermal Resistance

we know that $Q = \frac{-KA(T_2 - T_1)}{L}$

$\Rightarrow \frac{T_2 - T_1}{Q} = \frac{L}{KA} = R$

from Ohm's law $R = \frac{V}{I}$ $\frac{\text{Potential}}{\text{current}}$

Here incase of heat flow, Potential

$V = T_2 - T_1$ and current $I = Q$

Hence $\frac{L}{KA} = R_{thermal}$

The term L/KA is called Thermal Resistance.

Unit is hr-°c/Kcal

So $R_{thermal} = \frac{T_2 - T_1}{Q}$

(or)

$Q = \frac{T_2 - T_1}{R_{thermal}}$

Thermal Resistance :-

Thermal Resistance of a material or medium is defined as the Resistance offered by the material or medium to heat flow through it.

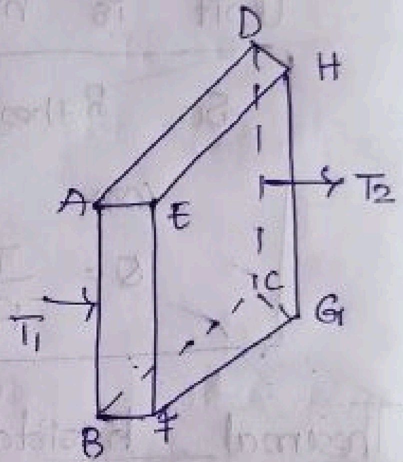
Explain and calculate the steady state heat conduction through flat walls and cylindrical walls.

Steady state heat flow

Steady state implies that temperature of the body varies with location not with time.

Heat Conduction through flat walls

Consider a rectangular flat wall ABCDEFGH in which heat is conducted ABCD to EFGH.



let A = Area of the face ABCD

T_1 = Tempr of the face ABCD

T_2 = Tempr of the face EFGH

x = distance between two faces

K = Thermal conductivity of the material wall.

Applying Fourier's equation of conduction

$$q = \frac{Q}{A} = -K\frac{(T_2 - T_1)}{x}$$

$$\Rightarrow Q = \frac{KA(T_1 - T_2)}{x}$$

Also this equation can be rearranged

$$Q = \frac{T_1 - T_2}{x/KA} = \frac{\text{Driving force}}{\text{Thermal Resistance}}$$

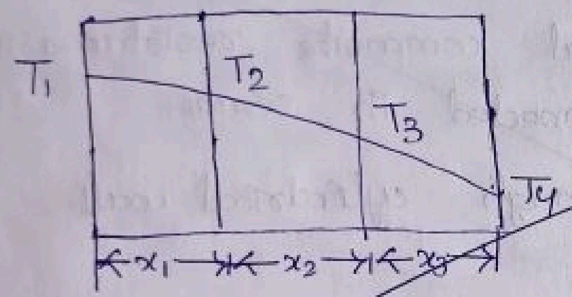
$$\boxed{Q = \frac{T_2 - T_1}{R_t}}$$

Heat conduction through composite plane wall

Consider a composite plane wall of three different material having thermal conductivity K_1, K_2 & K_3. (A) is the same area for each surface.

The thickness of the first material is x_1 and for second material is x_2 and for third material is x_3.

let T_1, T_4 be the temperature of the outer faces. and T_2, T_3 be the temperature of the interfaces. If $T_1 > T_4$, then heat is conducted from T_1 face to T_4 face.



According to Fourier's equation for heat conduction in layer one :-

$$Q = \frac{K_1 A (T_1 - T_2)}{x_1}$$

$$\Rightarrow (T_1 - T_2) = \frac{Q \cdot x_1}{K_1 A} \longrightarrow (1)$$

Similarly heat conduction is 2nd layer

$$Q = \frac{K_2 A (T_2 - T_3)}{x_2}$$

$$\Rightarrow (T_2 - T_3) = \frac{Q \cdot x_2}{K_2 A} \longrightarrow (2)$$

for 3rd layer, heat conducted is

$$Q = \frac{K_3 A (T_3 - T_4)}{x_3}$$

$$\Rightarrow (T_3 - T_4) = \frac{Q x_3}{K_3 A} \longrightarrow (3)$$

Adding the above eq^n ①, ② and eq^n ③, we get

$$(T_1 - T_2) + (T_2 - T_3) + (T_3 - T_4) = \frac{Q \cdot x_1}{K_1 A} + \frac{Q x_2}{K_2 A} + \frac{Q x_3}{K_3 A}$$

$$\Rightarrow T_1 - T_2 + T_2 - T_3 + T_3 - T_4 = \frac{Q}{A}\left[\frac{x_1}{K_1} + \frac{x_2}{K_2} + \frac{x_3}{K_3}\right]$$

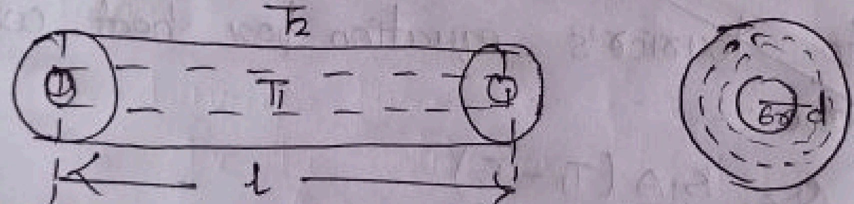
$$\Rightarrow T_1 - T_4 = \frac{Q}{A}\left[\frac{x_1}{K_1} + \frac{x_2}{K_2} + \frac{x_3}{K_3}\right]$$

Thus $Q = \dfrac{(T_1 - T_4)}{\left[\dfrac{x_1}{K_1 A} + \dfrac{x_2}{K_2 A} + \dfrac{x_3}{K_3 A}\right]} = \dfrac{T_1 - T_4}{Rt_1 + Rt_2 + Rt_3}$

$$\Rightarrow Q = \frac{\text{Thermal driving force}}{\text{Thermal Resistance.}}$$

Hence the individual composite resistances in composite wall is connected in series.

Heat conduction through cylindrical wall.



Consider a cylindrical pipe carrying a hot fluid at a temperature t_1 and its outer face is at a temperature t_2. So heat is conducted to the outer face from inner face.

let r_1 = Inner Radius of the cylinder.
r_2 = Outer Radius of the cylinder
x = Thickness of the wall.
K = Thermal conductivity of the wall
l = length of the cylinder

Consider elementary thin cylinder of Radius 'r' and thickness 'dr'. The change of temperature across the elementary cylinder is 'dt'.

Then applying Fourier's law of heat conduction, we have

$$Q = -KA \cdot \frac{dt}{dr} = -K(2\pi r l) \cdot \frac{dt}{dr}$$

$$\Rightarrow dt = \frac{-Q}{K(2\pi l)} \cdot \frac{dr}{r}$$

By integrating both sides, we get

$$\Rightarrow t = \frac{-Q}{K(2\pi l)} \log_e r + C$$

Applying Boundary condition $t = t_1$ at $r = r_1$ and $t = t_2$ at $r = r_2$

$$[t]_{t_2}^{t_1} = \frac{-Q}{K \cdot 2\pi l} \left[\log_e r\right]_{r_2}^{r_1}$$

$$\Rightarrow t_1 - t_2 = \frac{Q}{K 2\pi l} \left[\log_e r_1 - \log_e r_2\right]$$

$$\Rightarrow t_1 - t_2 = \frac{Q}{K 2\pi l} \log_e (r_1/r_2)$$

$$\Rightarrow \boxed{Q = \frac{K 2\pi l (t_1 - t_2)}{\log_e (r_1/r_2)}}$$ Imp

$$\Rightarrow Q = \frac{t_1 - t_2}{\frac{\log_e (r_1/r_2)}{K \cdot 2\pi l}} = \frac{t_1 - t_2}{R_t}$$

R_t = Thermal Resistance of the cylinder

$$= \frac{1}{K \cdot 2\pi l} \log_e (r_1/r_2)$$

For composite cylindrical wall $\Rightarrow Q = \dfrac{T_1 - T_4}{R_{t_1} + R_{t_2} + R_{t_3}}$

Convection

Convection is defined as the transfer of heat from hot part to cold part due to bodily movement of atoms of molecules of the medium. The heat transfer may be through free convection or forced convection.

Natural Convection

In free convection, movement of fluid is caused by temperature difference only. In free convection the circulation is caused by the difference in the densities of cold and heated particles of the fluid. When a hot plate is hanging in still air, the layer of air adjacent to the plate should be hotter than the surrounding. Hence this hot, lighter air would move upward setting up free convection.

The driving force in free convection, therefore, is the density difference between fluid layer adjacent to the solid and the fluid in the bulk.

The heat transfer rate is directly proportional to temperature difference between the hot surface and the steady bulk temperature.

$$q \propto (T_s - T_\infty) \qquad [\because q = \text{heat}]$$

$$q = h\,(T_s - T_\infty)$$

h = heat transfer co-efficient for convection heat flow.

Forced Convection

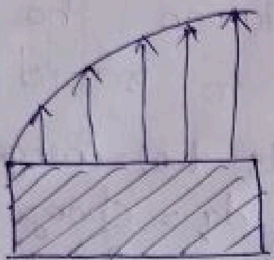
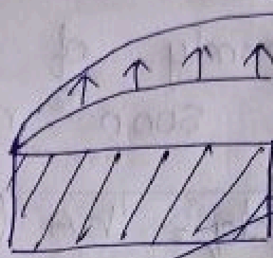
In forced, the flow of fluid is produced by an external means such as pumps, fans etc. since, the flow maintain by use of external force, here laminar flow condition is distributed and uniformly of temperature between the fluid is very soon maintained due to rapid mixing.

$$\boxed{dq = hA\,(t_s - t_\infty)}$$

$(t_s - t_\infty)$ = Change in temp
dq = Change in heat
A = Area

* Difference between Natural convection and Forced Convection.

	Natural Convection	Forced Convection.
(i)	The driving force natural convection is the temp difference between hot and cold point.	(i) The driving force for forced convection is the external force of pumps and fans etc.
(ii)	In this convection, the degree of mixing is less and hence nonuniformity is maintained in the fluid.	(ii) In this convection the degree of mixing is high and hence more temperature uniformity maintain in the fluid.
(iii)	The boundary layer thickness is greater and even laminar flow is maintained to the greater depth of the fluid.	(iii) The boundary layer thickness is very thin and hence the turbulency is maintained near the solid surface.

Natural convection	Forced convection.
(iv) The heat transfer co-efficient is small. hence rate of heat transfer is slow.	(iv) The heat transfer co-efficient is greater and hence the rate of heat transfer is higher.
	
Free convection boundary layer.	Forced convection boundary layer.

The Natural and forced heat transfer co-efficient

In a fluid, heat flow is due to both conduction and convection. If the flow is Turbulent, then, in addition of bulk flow, eddies are also responsible for mixing. If eddy exchange takes place in the presence of a temperature gradient, then this would lead to transfer of heat from higher to the lower temperature and is called eddy conduction.

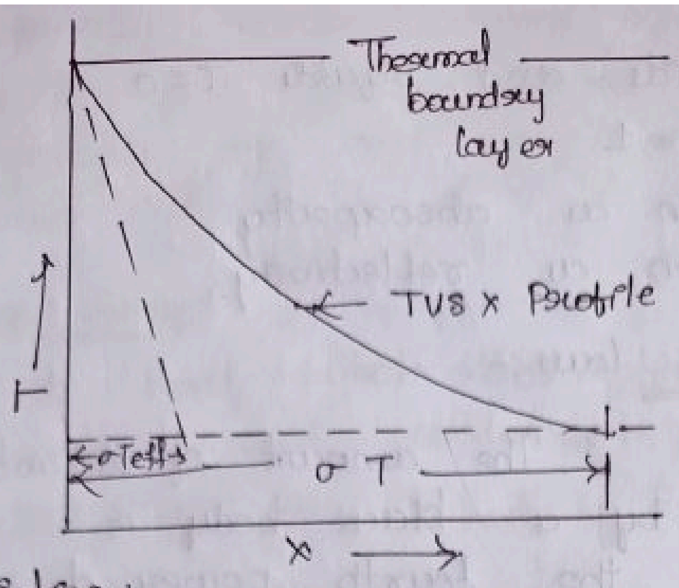
$$q_x = -\lambda \frac{dT}{dx} + \rho b u x = E\lambda \frac{dT}{dx}$$

$E\lambda$ = eddy conductivity

The heat transfer co-efficient due to convection is generally represented as 'h'.

$$\boxed{h = \frac{k}{\delta t_{effective}}}$$

δT_{eff} is called the effective thermal boundary layer.



Radiation :-

Radiation is the process of transmission of heat in which heat travels from one point to another in straight line, with velocity of light without heating the ~~intervening~~ medium. Energy is continually ~~radiated~~ ~~to~~ in the form of electromagnetic waves.

Principle - Already written.

According to the wave property velocity of electro - magnetic wave is written as

$$C = f\lambda$$

f = frequency of Radiation

λ = Wavelength.

Properties of heat Radiation :-

If a body recieves radient energy, a fraction fraction (α) is absorbed another ~~fraction~~ (ω) is reflected and a final fraction (τ) is transmitted.

$\alpha + \omega + \tau = 1$

For most of solids and liquids $\tau = 0$

hence $\alpha + \omega = 1$

α is known as absorptivity

ω is known as reflectivity.

Steffen Boltzman's law :-

This states that " The amount of radiant energy emitted by a black body is proportional to the fourth power of its absolute temperature.

$$E_0 \propto T^4$$

$$E_0 = \sigma_0 T^4$$

σ_0 = Radiation co-efficient of black body.

Emmisivity of Black Bodies and Grey Bodies

Black Body

A body that absorbs all the radiation falling upon it is called a Black Body, without regarding the wavelength of incident rays. (For black body $\alpha = 1$) There is no material which is perfectly Black. Since every body lose part of incident radiation by reflection or transmission. But it is possible to increase the absorbivity of Bodies upto 90-95%. for artificially creating Black Body. Consider a large hallow sphere or cylinder with a small opening when the radiation is allowed to incident through the opening, the incident rays are internally reflected several times on the inner surface and hence whole amount of radiation is absorbed by and only a small part is escapes out.

Grey Body

A body whose absorptivity does not vary with temperature and wavelength of incident ray, is called a grey body. For grey body emissivity power is less than 1.

Emmissive Power

The emissive power of a body is the thermal energy radiated from a unit surface of the body in a unit time for electromagnetic waves of wave length ranging from $\lambda = 0$, $\lambda = \infty$

Excellent A++

Keep working hard! Success in the way. ☺

3rd Chapter

FURNACES

* **Furnace :-**

A furnace is a device in which the chemical energy of fuel or electrical energy is converted into heat which is then used to raise the temperature of the material called burden or stock, placed with in it for that purpose. Furnace operating at low temperature are often called ovens.

Classification of the furnaces based on use, Heat source and movements.

* **Classification of furnace based on heat source.**

Depending on the fuel and electricity as the heat source, the furnace are broadly classify into two type :-

(i) Fuel fired furnace

(ii) Electric furnace.

Fuel fired furnaces

1. Solid fuel fired furnace → (Coal fired Boiler)
2. Liquid fuel fired furnace → (Rotary kiln)
3. Gaseous fuel fired furnace → (Coke oven, sinter furnace, Soaking pit, Re-heating furnace).
4. Multi fuel fired furnace → (Captive power plant boiler)

Electric furnaces

1. Electric resistance furnace.
2. Electric induction furnace
3. Electric arc furnace.

Advantages

1. Simple design, easier control.
2. No pollution and clean working system/condition.

Classification of furnaces Based on use.

1. Melting furnaces (Blast furnace)
2. Heating furnaces (Soaking pit, reheating furnaces)
3. Refining furnaces (LD converter, open hearth furnaces)
4. Heat treatment furnaces (Annealing furnaces, Hot Dip Galvanising line (HDGL) furnace)
5. Steam generating furnaces (e.g. Boilers)

Classification based on the mode of operation.

1. Periodic furnaces (coke ovens, annealing furnaces)
2. Continuous furnaces (Rotary kilns, Reheating furnaces)
3. Batch furnace (Cupola)

Classification based on the geometrical shape

1. Crucible furnace
2. Shaft furnace (e.g Blast furnace)
3. Hearth furnace.

Classification based on the use of heat saving application.

1. Recuperative furnaces (soaking pit)
2. Regenerative furnaces (coke oven)
3. Waste heat boiler type furnace (Rotary kiln)

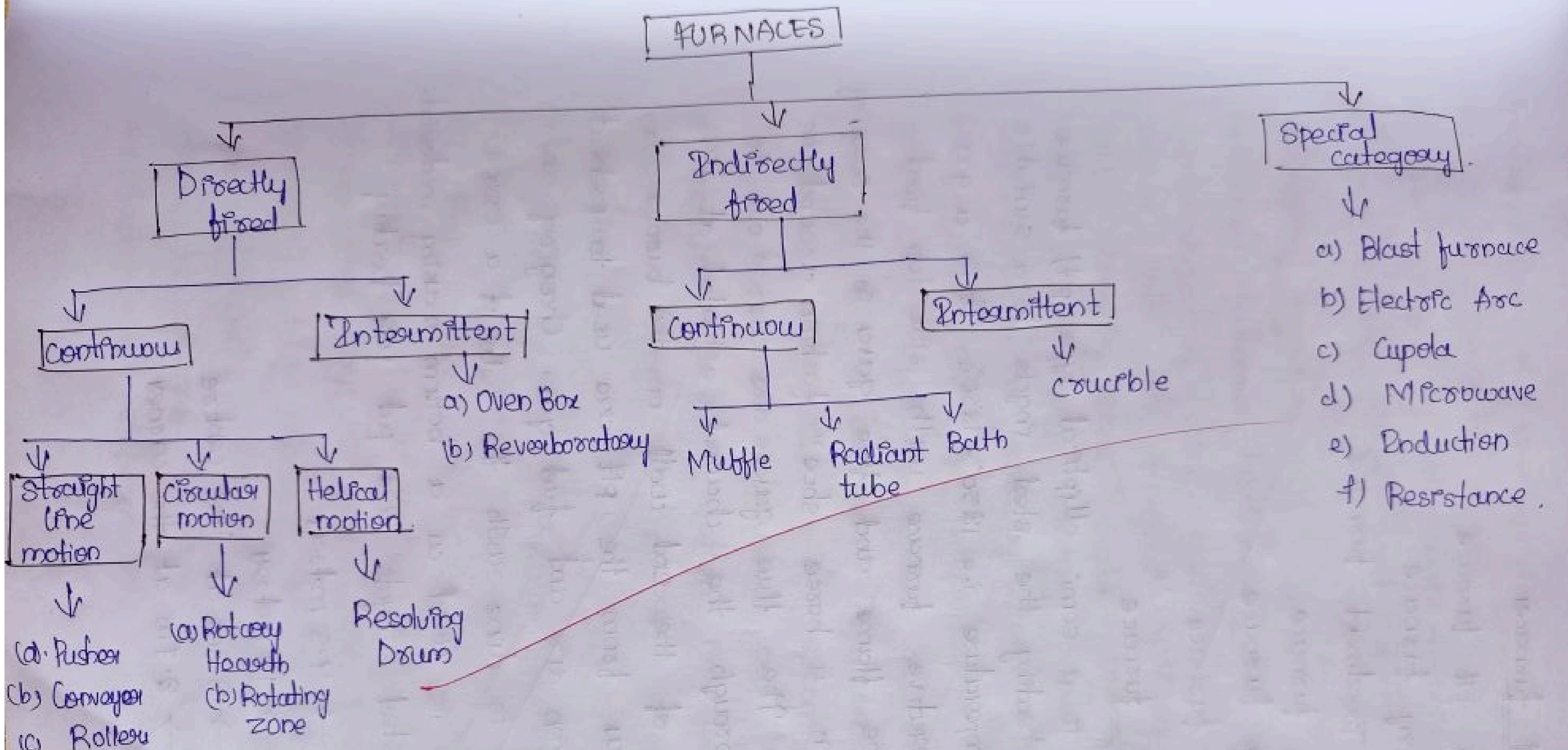
Classification based on movement of furnaces

1. Straight line motion.
2. Circular motion.
3. Helical motion.

* Helical motion :- The motion that is produced when one component of the velocity is constant in magnitude direction (i.e straight line motion) while the other component is constant in speed but uniformly varies in direction. (i.e circular motion)

→ Superposition of both is helical motion.

FURNACES


FURNACES
Directly fired
Continuous
Straight line motion
(a) Pusher
(b) Conveyor
(c) Rollers
Circular motion
(a) Rotary Hearth
(b) Rotating zone
Helical motion
Revolving Drum
Intermittent
a) Oven Box
(b) Reverberatory
Indirectly fired
Continuous
Muffle
Radiant tube
Bath
Intermittent
crucible
Special category.
a) Blast furnace
b) Electric Arc
c) Cupola
d) Microwave
e) Induction
f) Resistance.

* Metallurgical furnaces

(a) Soaking pit furnace
(b) Reheating furnace
(c) Heat Treatment furnace
(d) Melting furnace
(e) Smelting furnace
(f) Refining furnace.

Soaking pit furnace

Soaking pit is a semi-elliptical type pit/furnace used for heating the steel ingots to a suitable rolling temperature i.e 1250°-1280°c. It is a gas fired recuperative furnace with side top fired burner. The flame and flue gases in the soaking pit flow in "horse shoe" fashion around the steel ingot. The flue gases are carried out to chimney through the channel situated at the bottom part of the end wall on the burner side. Hot flue gas from the pit are used to preheat the combustion air and fuel gas. Charging and discharging is done with the help of a crane. Each breeze is used as a bottom making material on which steel ingots are put for heating.

Height ⟶ 4.5 meters
length ⟶ 10 meters
Width ⟶ 3.3m at the centre
⟶ 2.7m at the corner.

Refractory lining of soaking pit

(a) Pit cover ⟶ fire clay

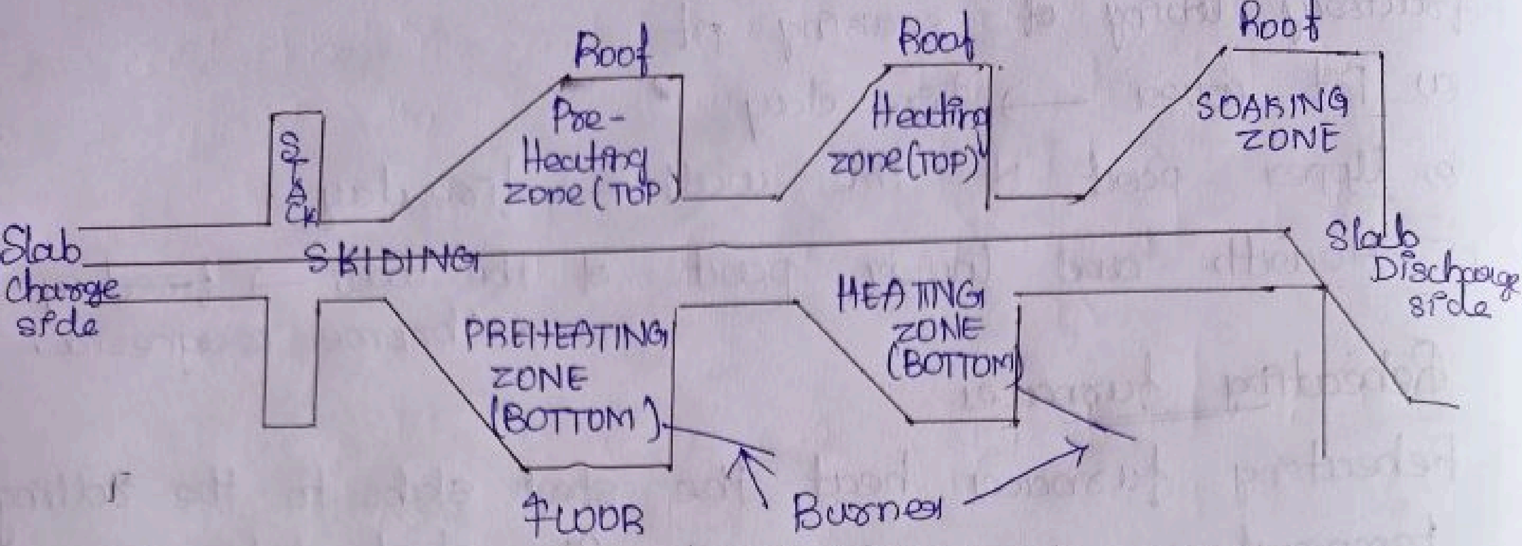
(b) Upper part of the wall ⟶ fire clay

(c) Hearth and lower part of the wall ⟶ ~~fireclay~~ Chrome magnesia.

Reheating furnaces

Reheating furnace heat the steel slabs to the rolling temperature of 1250°C – 1280°C. The steel slabs are pushed into the furnace by two pusher from slab charging side. Slabs travelled on cooled skid pipe through heating zones and then on a solid hearth in soaking zone. The furnace has five zones out of which four are called heating zones and fifth is known as soaking zone. There are total 59 burners. The combustion air is preheated at 500°C in a ceramic recuperator. The flue gases are exhausted out through stack. Evaporative cooling system is used for skid pipe cooling during which waste heat steam is produced.

Hot or cold steel slabs are heated in the reheating furnace to rolling temperature before hot rolling it. Hot rolling of steel refers to plastic deformation of metal above its recrystallisation temperature by squeezing it between a pair of rollers to produce hot rolled strips in the form of coil, slab reheating before its rolling is done to achieve higher plasticity and minium resistance to deformation.



Heat Treatment furnaces.

1) Annealing furnaces

a) Hood Annealing furnace (batch type).

b) Continuous annealing line furnace (continuous type)

2) Hot Dip Galvanising line (HDGL) furnace

a) Melting furnace

b) Blast furnace

c) Sintering furnace

d) Dwight Lloyd Sintering machine

e) Refining furnaces

f) (LD/ open hearth)

Excellent

4th chapter [V.V. Imp]

ELECTRIC FURNACES

Electric furnace

Electric furnaces are of three types:-

(i) Resistance furnace

(ii) Induction furnace

(iii) Arc furnace.

Electric Arc furnace

The temperature of an electric arc using carbon electrodes exceed 4000°c and hence steel making temperatures can be readily maintained in an arc furnace.

Arc furnaces are of two types, namely the indirect and direct arc furnaces. In direct arc furnaces, arc is struck between the two carbon electrodes and heat is transferred to the charge by radiation. These furnaces are used for scrap melting in ferrous foundries.

Electric Direct Arc furnace (3 - Electrode)

Construction

(i) A Direct Arc furnace consists of a heavy steel shell lined with refractory bricks and silica for acid furnaces and magnesite for basic lined furnaces. Basic refractories are costlier than acid refractories.

(ii) The roof of the direct arc furnace consists of a steel roofing in which silica bricks are fixed in position. The roof is a domed shape construction. The roof has three holes located symmetrically to allow insertion of electrodes.

(iii) The electrodes are either of carbon or graphite and are capable of carrying current at high density.

(iv) Large transformers are required to run electric arc furnace. The primary voltage may be 33kV or more.

(v) Generally a gap is left at the proper place while laying the bricks for making the tap hole. Smaller furnaces have only one door directly opposite to the tap hole and any additions during refining are made through this wall.

Operation

(i) Furnace Preparation :- After tapping the previous heat, the slag is completely drained out and the lining f/c is inspected in it. The end portion, the door, the tap hole, the spou stack and the damaged area of the hearth are all repaired in hot and by using granular dolomite magnesia. After that the interior of the furnace is preheated before placing the metal charge in the furnace.

(ii) Charging :- Charging is generally done from the top of electric arc furnace. Furnace roof is swing to one side, charging is done through drop bottom type charging bucket, with the help of cranes. Small amount of raw materials may be charged into the f/c. The charge consists of steel scrap, lime, spar, mill scale, coke and other alloying steel element

(iii) Melt Down

After charging is over, the roof is replaced in position, the electrodes are lowered. Electric arc is struck between the electrodes and the surface of the metal charge and the electrodes are put on automatic control. As the metal just below the arc melts and drips down, the electrodes automatically travel further down to maintain stable arc.

(iv) Three arcs burning simultaneously produce a temperature of the order of 1100°c and readily ~~mes~~ melt flux, and the metal scrap. The presence of lime in the charge helps to form slag during melting. Slag present on the top of the molten metal bath reduces its oxidation, refines the metal. The presence of lime in slag protects the lining from being attacked. Heat developed in the arc furnace should be utilized by the charge as far as possible. Excess heat is reduced to the furnace lining and damage it.

(v) Before pouring the liquid metal into the ladle, the furnace is tilted backward and the slag is poured off from the charging door.

(vi) The furnace is the tilted forward and the molten metal is tapped into laddles. Then the furnace is again repaired and next heat is started.

Advantages

1. Arc furnace is best suited for production of steels from any quality of all solid charges.
2. This is the most economical method of utilizing alloy steel scrap.
3. Better heat and temperature control.
4. Thermal Efficiency is about 70%
5. It is not difficult to control the furnace atmosphere.
6. Alloying elements like Cr, Ni, W can be recovered from the scrap.

Disadvantages

1. Heating costs are higher than other furnaces.
2. Heat losses during process

Uses

For making high quality carbon steels and alloy steels

High Frequency Induction Furnace

Construction (Coreless Induction Furnace)

① A high frequency induction furnace consists of a refractory crucible placed centrally inside water cooled copper coil and packing into position by ramming dry refractory highly between crucible and the copper coil.

(ii) The charge is placed in the crucible and it acts as the secondary winding. The crucible is surrounded by several turns of water cooled copper tubing which carries the high frequency primary current.

Operation :-

(i) Steel scrap is placed in the furnace as metal charge.

(ii) A high frequency current is passed through the copper coil. Heavy alternatively secondary current is thus induced in the metal charge by electromagnetic induction, create heat because the metal charge offers resistance to the passage of secondary current. This heat developed in the skin of the metal charge reaches inside by conduction and melts the charge.

(iii) The secondary current associates with in a magnetic field which provides a magnetic stirring action on the molten metal, speeds up the melting process and mixes up the metal charge uniformly.

(iv) The time taken to melt is very short. A thin layer of slag is maintained on the surface to prevent oxidation of the bath by oxygen. Slag is an insulator, hence is not heated by induction.

(v) Once melted, the metal is deoxidised and poured into laddle by tilting the furnace or by lifting away the shell along with coil.

Advantages

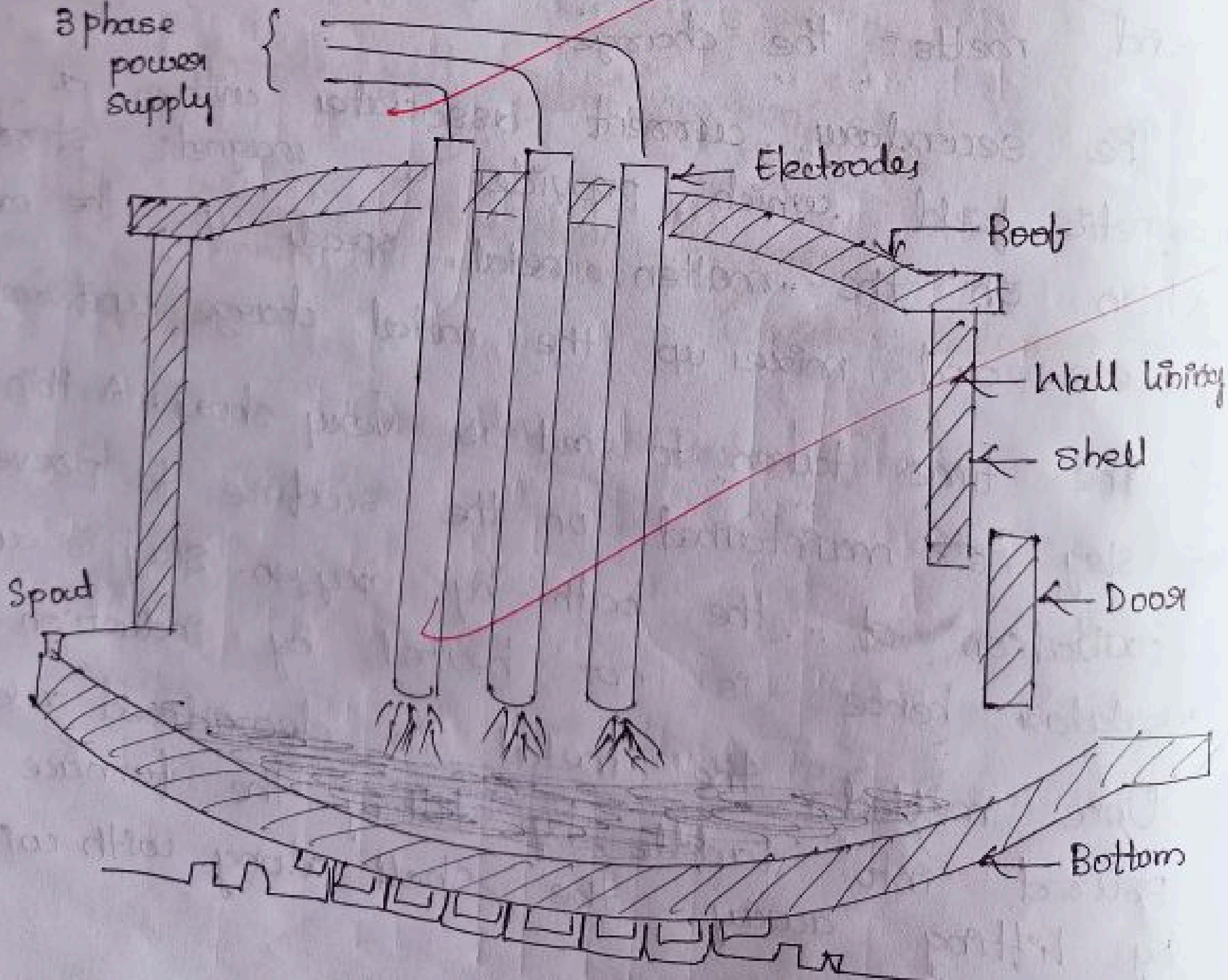
1. Excellent uniformity of melt composition.
2. Rate of energy input can be readily controlled.
3. Furnace atmosphere can be easily controlled.
4. These furnaces do not need a warming up time.
5. Addition of alloying elements like Ni, Co, Cr, W, Mo can be made easily.

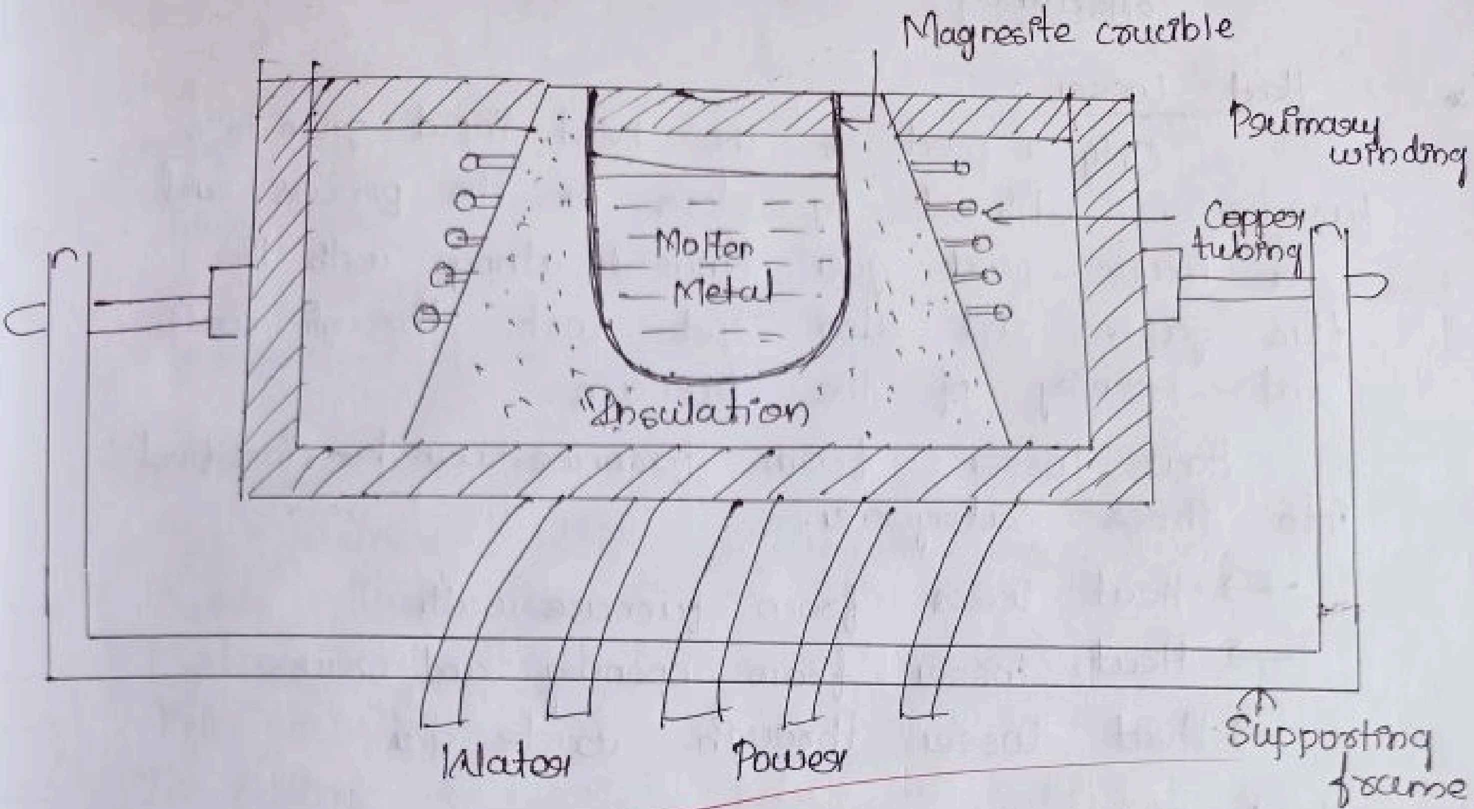
Disadvantages

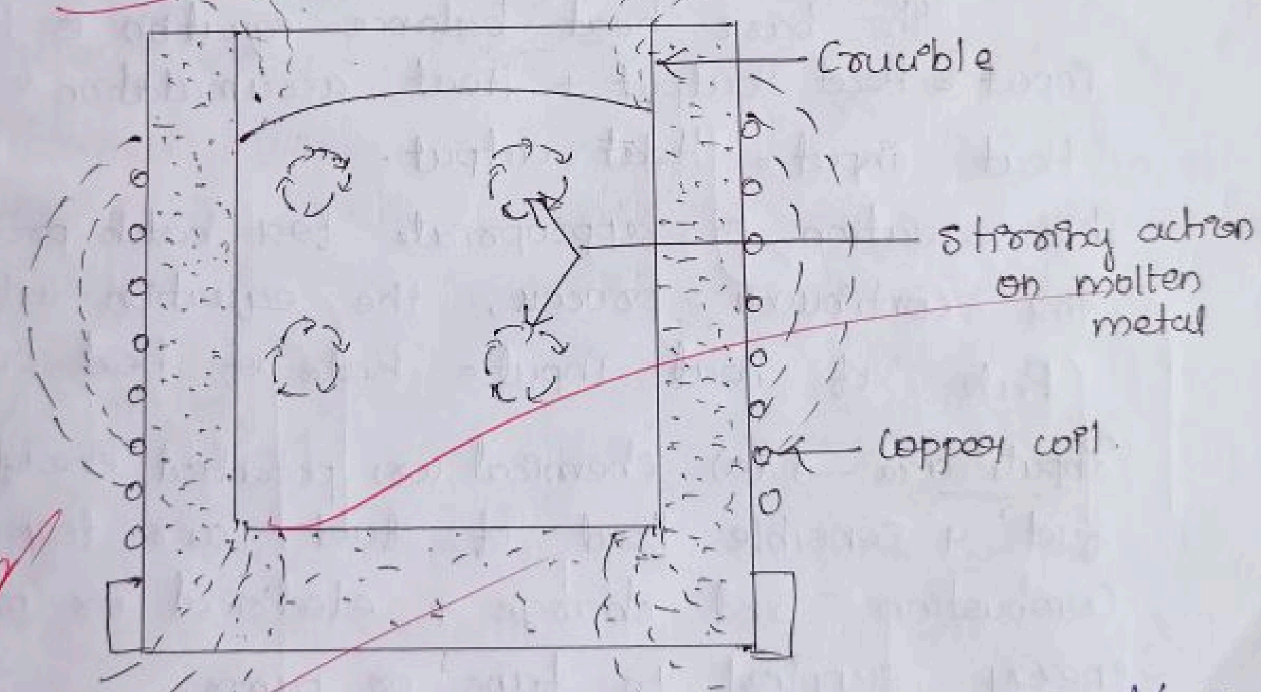
1. Initial cost of the furnace is high.
2. As the process is very fast, there is little time available for analysing the melt composition.

Application:-

Used for melting general, special, alloy and high quality steels in small quantities.







Principle of electric induction furnace :- Heating induction f/c is achieved by transformer action. An a.c of high frequency is applied to the coil (acts as primary coil) which induced secondary current in the charge funparsed Crucible acts as secondary coil. The resistance if the metal to flow of current.

5th chapter

Heat losses, Heat balance and furnace efficiency

* **Heat Losses :-**

Only a part of the heat input given to a furnace is utilized by stock or the process and a major part goes unused along with the flue gases and also get lost through walls and opening of the furnace.

Heat losses from furnace can be classified into three categories.

→ Heat losses from furnace walls
→ Heat losses from opening and cracks
→ Heat losses through waste gas.

* **Heat Balance :-**

The basic heat balance equation is Heat input = Heat output + Heat accumulation (or)
Heat input = Heat output.
This equation is appropriate for batch process.
for continuous process, the equation will be
Rate of heat input = Rate of heat output

Inputs are → (a) Chemical (or) potential energy of fuel + sensible heat of fuel, air for combustion and charge + electrical or mechanical energy supplied to fans or pumps.

(b) Heat evolved due to exothermic reaction.

Heat output

(i) Total heat content of outgoing material.

(ii) Heat absorbed in endothermic reaction or in phase change or in raising temperature.

(iii) Total heat of the exit gases.

(iv) Heat losses through walls, roofs, cracks and fissures by conduction and radiation.

Furnace Efficiency :-

The furnace efficiency depends upon -

- Flame Temperature
- Furnace Structure
- Air / gas Ratio
- Insulation levels of furnace
- Method of furnace operation
- Radiation losses from furnace

Thermal efficiency of a furnace is the ratio of the quantity of heat utilized to the total quantity of heat supplied. It varies in wide ranges 10-90 %.

Equation of Fanning :-

$$E_f = 2f\left(\frac{l}{D}\right)\bar{v}^2$$

E_f = Frictional energy.

Newton's law of cooling :-

It states that " Heat transfer from a hot body to a cold body is directly proportional to the surface area and difference of temperature between the two bodies.

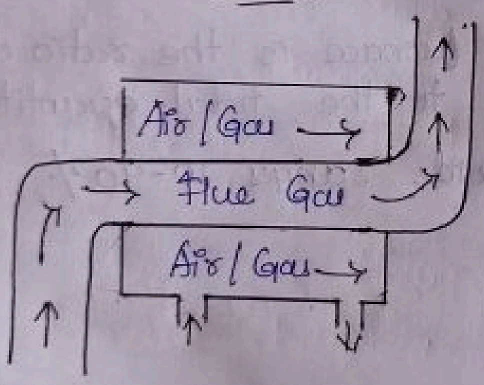
Thermal Conductivity :-

The quantity of heat in joules that flows in one second through one meter cube of a material when opposite faces are maintain at a difference of 1°K.

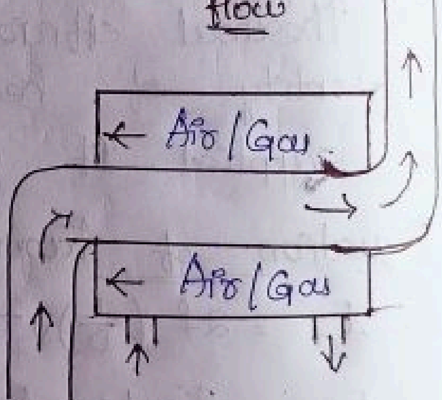
→ Parallel or co- current flow
→ counter current flow
→ cross flow.

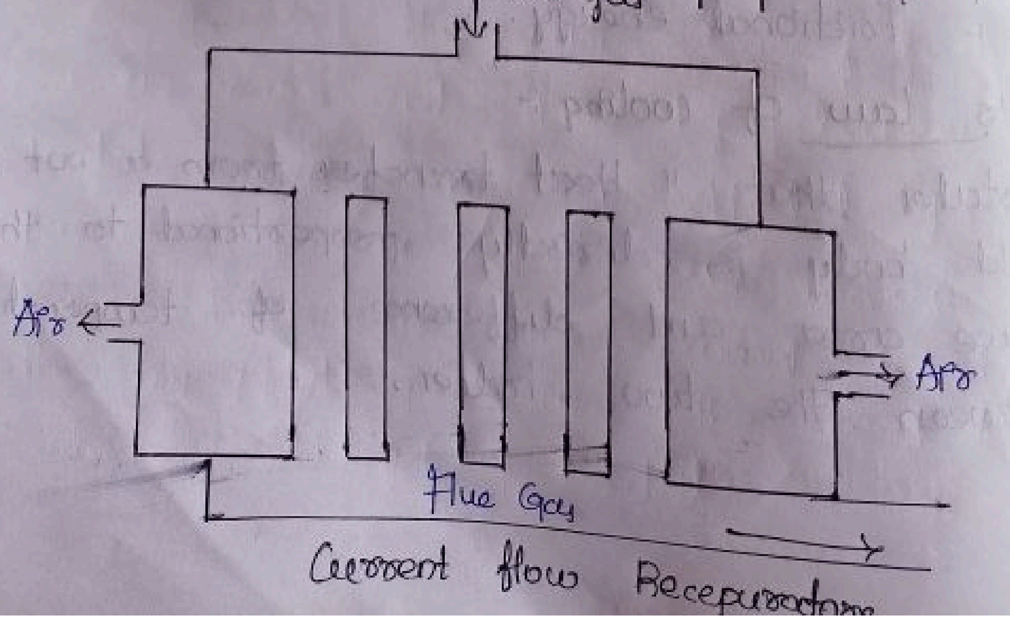
In the parallel flow both the hot and cold fluids flow in the same direction and heat is transferred during the flow. In the counter-current flow, the fluids move in opposite direction. In cross flow, the fluids move at right angles to each other. The counter flow ~~rep~~ receperators are most efficient.

Parallel flow



Counter-Current flow





Current flow Receperators

Waste...

Heat losses :-
Heat loss...
three c...
(i) Heat los...
(ii) Heat los...
(iii) Heat l...

4 Recuperat...
i) Recuperat... metallic
ii) Heat tra... cooler ... in which ... mix ... metalli...
iii) In re... betwee... meta...
iv) In ... thro... They ...
v) A r... exc... or ... ar...

6th chapter

Waste Heat Recovery System

* Heat losses :-

Heat losses from furnace can be classified into three categories.

(i) Heat loss from furnace wall.
(ii) Heat loss from Opening and Cracks
(iii) Heat loss through waste gases.

* Recuperator

(i) Recuperators are heat exchangers made from either metallic tubes or refractory channels.

(ii) Heat transfer from a hot fluid stream to a cooler / colder stream is done in heat exchanger in which the two streams are not allowed to mix each other as they are separated by metallic membrances.

(iii) In recuperator, the heat exchange takes place between the flue gases and air through metallic or Ceramic walls.

(iv) In this heat exchanges, One fluid moves through the tubes and other through the cell They are continuous in operation.

(v) A receperator may be considered as a heat exchanger transferring heat across a furnace on One side of which flue gas flows and at the other combustion air.

Recuperation is normally used on large furnace due to the high capital cost.

The recuperators are of following type -
The air or fuel gas can be preheated very near to the incoming temp. of the flue gases and temp. difference b/w the hot & cold fluids is almost constant throughout the length of passage.

* Regeneration

The flue gases and the air to be heated are passed alternatively through checkers, are there by resulting in transfer of heat.

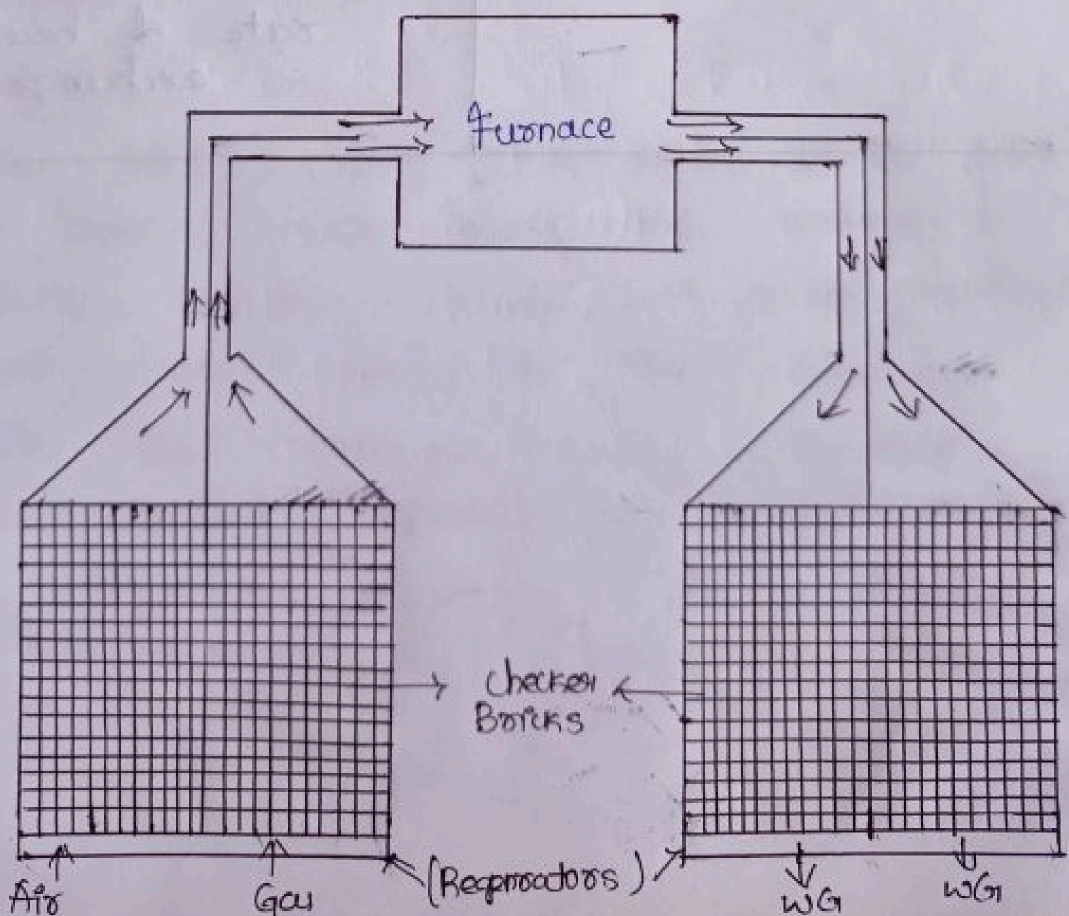
Regenerators are heat exchangers constructed of refractory bricks and operated in pairs. The bricks are so arranged that gases can flow with low pressure drop through them.

The chambers are operated in cycles of alternative heating and cooling. Heating of the chambers are effected by the hot flue gas flowing downward while leaving the furnace chamber.

The hot flue gases releasing heat to the checker bricks and there by checkers are heated. Cooling is then effected by the passage of air / fuel gases through heated checker bricks in the upward direction. So the air / fuel gas take the heat from checker and get preheated.

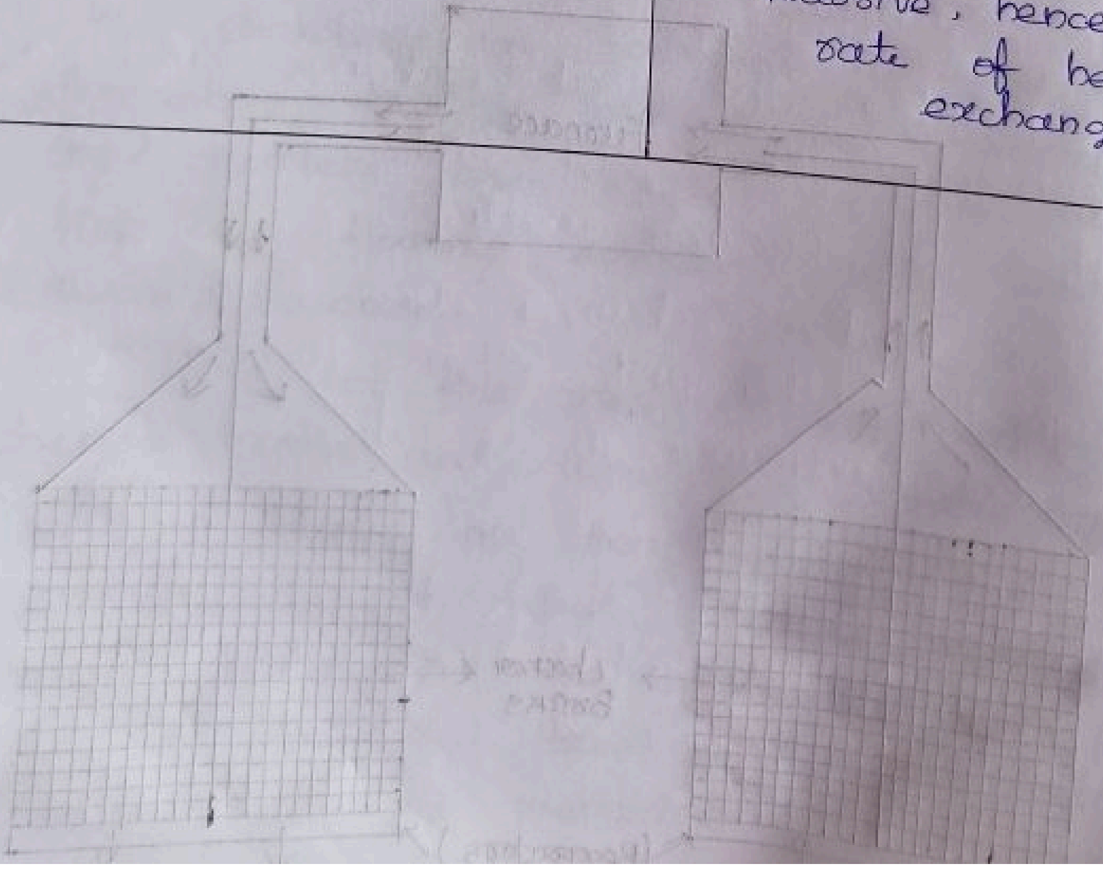
In the below figure through the left hand chamber air and fuel gas are flowing separated and air being heated through transfer of heat from checker works. They are on the cooling cycle. The right hand chamber through which the hot flue gases are passing are being heated from top to bottom. They are on heating cycle.

- Blast furnace are special type of regenerators used in steel industry to preheat the air for the blast furnace. In these stoves blast furnace gas is burned in the burning chamber and heat the checker work. Then air is passes through the hot checkers. There by the airblast is preheated. Temp of the air rised to more than 1000°C.



Difference between Recuperator and Regenerator.

Recuperator	Regenerator
1. Size is smaller compared to Regeneration	1. Big size and shape.
2. Used only in large scale industry.	2. Used only in steel industries and in coke oven.
3. Capital cost is less than regenerator.	3. Capital cost is high.
4. Continuous operation.	4. Cyclic operation (or) intermittent operation.
5. It can exchange less heat	5. It can store large quantity of heat.
6. Thin metallic walls facilitate rapid heat transfer.	6. Checker bricks are heavy bulky and massive, hence slow rate of heat exchange.



Thermal Radiation :-

Thermal Radiation is defined as the energy transferred by the electromagnetic wave that originate from a body because of its temperature.

→ The Rate at which the energy is emitted depends on the substance it self, surface condition and the surface temperature.

Emitance (e)

Emitance is the total emission power of a hot body in to the space around its entire volume is known as emitance. It is the flux of Thermal Radiation into the entire volume ~~are~~ around the body.

Irradiation (G)

The total Irradiation (G) of a body is defined as the flux of Thermal Radient energy ~~is~~ coming to the surface.

Radiosity :-

The total Radiosity (J) is defined as the total flux of radient energy leaving the surface of the body. Radiosity includes both energy emitted and both energy reflected to the surface.

→ The total increasing energy i.e, irradiation can be absorbed, reflected or transmitted from the body.

Total Irradiation (G) =
$\alpha G + \beta G + \gamma G$

where $\alpha + \beta + \gamma = 1$

α, β & γ are Definite terms

α = Absorbtivity i.e, the fraction of

Stefen Boltz Man's law

This law states that " The amount of radiant energy emitted by a black body is proportional to the fourth power of its absolute temperature

$$E_0 \alpha T4$$

$$E_0 = 6_0 T^4$$

where 6_0 = Radiation co-efficient of black body.

Terminal Velocity:-

Terminal velocity is defined as the maximum velocity of the particle when net force acting on the particle is zero.

- When an object is immersed in a fluid, it is acted upon by the opositively natured forces. The downward force acting upon it has a fixed value while the upward force due to particle movement is function of its velocity. A critical point is reached where upward resistance force and downward resistance force balance each other.

At this point particle attains a maximum velocity. This velocity is known as the terminal velocity.