The Shirpur Education Society's

R. C. Patel College of Engineering and Polytechnic, Shirpur

Department of Mechanical Engineering

NAME OF COURSE: - Thermal Engineering (TEG)

CODE OF COURSE: - 313310

SEMESTER: - SYME-3K

SUBJECT TEACHER: - Mr. Bhushan S. Patil

The Shirpur Education Society's

R. C. Patel College of Engineering and Polytechnic, Shirpur

QUESTION BANK

CHAPTER 4 Heat Transfer & Heat Exchangers

Program Name: Mechanical Engineering
Program Code: ME3k
Name of Subject & Code : Thermal Engineering (313310)
Semester : Third
Date & Time Slot: 02 /06/2026

Q. NO.	QUESTION	DETAIL	MAPPING
1	Define various modes of heat transfer with suitable example.	W24 Q4 A 4M	CO 4.1 R
2	Explain the Fourier's law and Newton's law of cooling related to heat transfer.	S 25 Q4 A 4M	CO 4.1 U
3	Define thermal conductivity and state it's unit.	W-25 / W24 Q1 2M	CO 4.1 R
4	Define transmissivity and Reflectivity.	W-25 Q4 D 4M	CO 4.1 R
5	Define the terms – i) Black body ii) Absorptivity.	S 25 Q2 F 2M	CO 4.1 R
6	State classification of heat exchangers. List any four applications of heat ex-changer.	W-25 Q5 C W24 Q6 B 6M	CO 4.2 R
7	Suggest the type of heat ex-changer required for steam power plant. Explain its working with neat label sketch.	S 25 Q4 B 4M	CO 4.2 A
8	Determine the rate of heat transfer through a composite wall made of 25 mm thick steel plate and covered with insulating material of 7 mm thick on one side. Thermal conductivity of steel and insulating material is 58 W/mk and 0.116 w/mk respectively. The temperature at the inner and outer surface of the wall is 280°C and 40°C respectively.	W-25 Q2 4M	CO 4.1 A
9	Determine the rate of heat flow through the boiler wall made of 2 cm thick steel and covered with an insulating material of 0.5 cm thick. K(steel) = 58 w/mk, K(insulation) = 0.116 w/mk. the temperature at the inner and outer surfaces of the wall are 300°C and 50°C respectively.	W24 Q4 A 4M	CO 4.1 A
10	A 100 mm thick brick wall measuring 5m × 3 m is insulated Externally by cork 80 mm thick which is further protected by wood 25 mm thick. If the interior wall temperature is - 5°C and outer wall temperature is 15°C. Determine the heat transfer through the wall per hour. Take thermal conductivities of brick, cork and wood as 0.7, 0.05, 0.20 KW/m°C respectively. Also find temperature at inner surfaces.	S 25 Q6 B 6M	CO 4.1 A
11	Explain the Stefan Boltzmann law related to heat transfer.	OTHER	CO 4.1 U
12	Explain the construction and working of shell and tube type of heat exchanger.		CO 4.1 U
13	Explain the construction and working of plate type of heat exchanger.		CO 4.1 U
14	Give difference between forced convection and natural convection.		CO 4.1 A
15	Enlist application of heat exchanger.		CO 4.2 R

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Chapter-04

Heat transfer & heat Exchanger

Total Hrs = 06
Total Marks = 12

Q. =	Q.4 A & B	Q6	Q.1
Mark =	(8M)	(6M)	2M

4.1 Modes of heat transfer :-

Transmission of Energy from one region to another region as a result of temperature difference.

Three modes of Heat transfer.

a) Conduction b] Convection c] Radiation.

a] Conduction :-

It is a mode of heat transfer where heat is transfer from one part of substance to another part of the same substance without any appreciable movement of molecules forming the substance.

- Heat transfer takes place by vibratory motion from one electron to another electron.

eg. Heat transfer across the wall from outer surface to inner surface.

fouriers law of Heat transfer :-

Heat transfer through an object is directly proportional to the area perpendicular to direction of heat flow & temperature difference between two surfaces & inversaly proportional to the distance.

$$\therefore \left.\begin{array}{l} Q \propto A \\ \propto dT \\ \propto \frac{1}{dx} \end{array}\right\} \Rightarrow \begin{array}{l} Q = -kA\frac{dT}{dx} \\ \therefore \frac{Q}{A} = -k \cdot \frac{dT}{dx} \end{array}$$

where, $\frac{Q}{A}$ = heat flux [J/m^2] $\cong$ [W/m^2]

$\frac{dT}{dx}$ = temperature gradient [$^oC/m$]

that is, "The rate of change of heat flux due to conduction in any direction is proportional to the temperature gradient present in that direction.

where, Q = Heat flow in watt

A = Area Normal to heat flow in m^2

$\frac{dT}{dx}$ = Temperature gradient in $^oC/m$

k = Thermal conductivity in W/mK.

"$-$ve" sign indicates heat flow from high temperature to low temperature.

Thermal Conductivity [K]:-

It is a heat transfer through a unit area of unit thickness & having unit temperature difference.

$$\therefore \quad K = \frac{[Q/A]}{[dT/dx]}$$

Here, $A = 1m^2$

$dT = 1^oC \cong 1^oK$

$dx = 1m$.

$\therefore$ $\boxed{K = Q}$ in W/mK

copper is having Higher thermal conductivity as 380 W/m°K. &

polysterene = 0.035 W/m°K - good insulator.

K_{steel} = 50 W/m°K.

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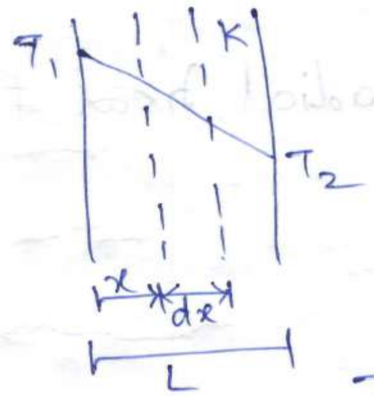
* Heat flow through slab [of wall]

consider wall of length L having surface temp T_1 & T_2 respectively. $T_1 > T_2$

Let A be the cross-sectional area of the wall & K be the thermal conductivity of wall material



Therefore, from Fourier's law of heat flow in 'x' direction is given as.

$$Q = -KA\frac{dT}{dx}$$

$$\therefore dx\frac{Q}{A} = -K\,dT$$

The Boundary conditions are.

(i) at $x=0$, $T=T_1$ & (ii) at $x=L$ $T=T_2$

$$\therefore \int_0^L \frac{Q}{A}dx = -\int_{T_1}^{T_2} K\,dT$$

$$\therefore \frac{Q}{A}\int_0^L dx = -K\int_{T_1}^{T_2} dT$$

$$\therefore \frac{Q}{A}[x]_0^L = -K[T]_{T_1}^{T_2}$$

$$\therefore \frac{Q}{A}L = -K[T_2 - T_1]$$

$$\therefore \boxed{Q = \frac{KA[T_1 - T_2]}{L}}$$

* Heat flow through Hollow cylinder

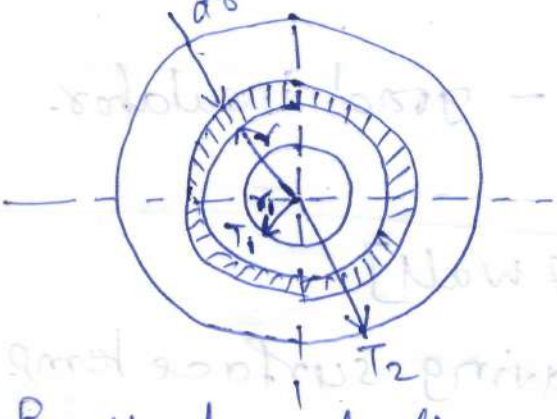


fig. Heat conduction through Hollow cylinder

consider a hollow cylinder of length L with inner & outer radii as r_1 & r_2.

The temperatures of the inner & outer surfaces are maintained at T_1 & T_2 resp.

Let K be thermal conductivity of the material & A be the surface area of the cylinder

∴ surface area, $A = 2\pi r L$

∴ The fourier's equation for radial heat flow is given as,

$$Q = -KA\frac{dT}{dr}$$

$$\therefore \frac{Q}{A} \cdot dr = -K\,dT$$

$$\frac{Q}{2\pi L r}\,dr = -K\,dT$$

∴ Integrating between the Boundary conditions

i] at $r = r_1$, $T = T_1$ ii] at $r = r_2$, $T = T_2$

$$\therefore \int_{r_1}^{r_2} \frac{Q}{2\pi r L} \cdot dr = -\int_{T_1}^{T_2} K\,dT$$

$$\therefore \frac{Q}{2\pi L} \cdot \ln[r]_{r_1}^{r_2} = -K[T_2 - T_1]$$

$$\therefore \frac{Q \cdot \ln[r_2/r_1]}{2\pi L} = K[T_1 - T_2]$$

$$\therefore \boxed{Q = \frac{2\pi L K[T_1 - T_2]}{\ln[r_2/r_1]}}$$

2] Convection:→

Convection is the mode of Heat transfer, in which, physical circulation of molecules takes place.

In which Heat transfer takes place between solid surface & adjacent liquid or gas, which is in motion.

Heat transfer equation is given by Newton's law of cooling.

$$\therefore \quad Q = hA\,dT$$

where, h = convective Heat transfer coefficient in W/m^2K

A = surface area in m^2.

ΔT = Temperature difference in °C or °K

eg:⇒ Boiling of water in Boiler.

* Types of convection

① Free convection	② Forced convection
① circulation of water takes place by density difference	① circulation of water takes place by mechanical devices eg. fan, blower etc
② rate of heat transfer is less	② rate of heat transfer is increased by ~~fan or~~ forced circulation of fluid.
③ eg. A] flow of Hot gases in a chimney [Natural draught]. B] flow of hot air along a road in summer season.	③ A] eg. condenser in steam power plant. B] Evaporator in Refrigerating unit.

Thermal Resistance

The flow through walls is given as,

$$Q = \frac{KA[T_1 - T_2]}{L}$$

$$\therefore Q = \frac{T_1 - T_2}{[L/KA]} \quad - (1)$$

we know, for electric circuit, flow of current is given as. $I = \frac{E_1 - E_2}{R} \quad - (2)$

Both equations (1) & (2) are analogus.
Here $[T_1 - T_2]$ is known as thermal potential & L/KA is known as thermal Resistance.

$\therefore$ Thermal Resistance $\boxed{R_t = L/KA}$

$$\text{Unit} \Rightarrow \frac{m}{\left(\frac{W}{mK} \cdot m^2\right)} \Rightarrow {}^0K/W \text{ or } {}^0C/W$$

eqn (1) can be written as.

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

$\therefore R_{th} = \frac{T_1 - T_2}{Q} \Rightarrow$ "amount of temperature difference required for unit heat flow rate"

for Hollow cylinder.

$$Q = \frac{2\pi LK[T_1 - T_2]}{\ln[r_2/r_1]}$$

$$= \frac{T_1 - T_2}{\left[\frac{\ln[r_2/r_1]}{2\pi LK}\right]}$$

$$\therefore \boxed{R_{th} = \frac{\ln[r_2/r_1]}{2\pi LK}}$$

for convection :→

$[R_{th_c}] \Rightarrow \frac{1}{hA}$

Heat flow rate by convection is given by

$$Q = hA\,(T_1 - T_f)$$

$$\therefore Q = \frac{[T_1 - T_f]}{[1/hA]} = \frac{T_1 - T_f}{[R_{th_c}]}$$

$$\therefore \boxed{R_{th_c} = \frac{1}{hA}}$$

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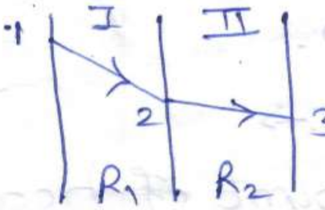
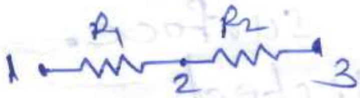
for composite wall,

$R_{th} = ?$

① series combⁿ :→



$R_{th} = R_1 + R_2 = R_{eq}$.



② ||el combination :→

$\cancel{R_{eq} = R_1 + \left[\frac{1}{R_2} + \frac{1}{R_3}\right]}$

$\cancel{\therefore R_{eq} = R_1 + \frac{R_3 + R_2}{1}}$

$$\therefore \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\therefore \frac{1}{R_{eq}} = \frac{R_2R_3 + R_1R_3 + R_1R_2}{R_1R_2R_3}$$

$$\therefore R_{eq} = \frac{R_1R_2R_3}{R_2R_3 + R_1R_3 + R_1R_2}$$

Overall Heat transfer coefficient.

Heat transfer through composite wall is given by $Q = UAdT$, by considering all mode of Heat transfer

where U = overall Heat transfer coefficient.

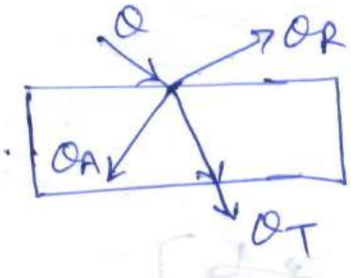
3] Radiation

Radiation is the transfer of heat through space by means of thermal radiation or electromagnetic waves.

It is takes place ~~by~~ between two Bodies by without any carrying medium.

It is mostly fast in vaccum.

Terms related to Radiations:→



Let Q be the amount of heat falling on the surface.

Q_R = Heat reflected

Q_A = Heat absorbed

Q_T = Heat transferred

1] absorptivity (α) = "fraction of total amount of energy falling on the surface, which is absorbed."

$$\boxed{\alpha = \frac{Q_A}{Q}}$$

2] Reflectivity [r]:– "fraction of total amount of energy falling on the surface, which is reflected."

$$r = \frac{Q_R}{Q}.$$

Transmitivity :-

"Fraction of total amount of Energy falling on the surface, which is transmitted."

$\therefore \tau = \frac{Q_t}{Q}$

$\therefore Q = Q_A + Q_R + Q_T$

$\therefore 1 = \frac{Q_A}{Q} + \frac{Q_R}{Q} + \frac{Q_T}{Q}$

$\therefore \boxed{1 = \alpha + r + \tau}$

Types of body :-

a] Black body :-

It is idealised physical body, that absorbs all electromagnetic radiations falling on it.

For black body, $\boxed{\alpha = 1}$, $\boxed{\tau = 0 = r}$

b] opaque body :-

The bodies, which has negligible transmitivity of Energy.

$\boxed{\alpha + r = 01}$ & $\boxed{\tau = 0}$

c] white body :-

The bodies which reflects all radient energy falling on it. $\boxed{r = 1}$ $\boxed{\alpha = \tau = 0}$

d] Grey Body :-

Body having values of α, r & T in between 0 to 1

v] Transparent body:-

The surface which transmit the entire radiations falling on it. $\boxed{\tau = 1}$ or $\boxed{\alpha = r = 0}$

vi] Emissive power [e]:-

Energy radiated per unit time per unit area from the surface of body at a certain temperature unit $\Rightarrow$ W/m^2.

vii] Emissivity [ε]:-

The ability of the surface of a body to radiate heat.

It is a ratio of emissive power of a surface to emissive power of a black body when they are at same temperature.

$$\boxed{\varepsilon = \frac{e}{e_b}}$$

for black body, $\varepsilon = 1$
for white body $\varepsilon = 0$

Stefan Boltzmann Law:-

Emmissive power of black body is directly proportional to fourth power of absolute temperature.

$$e_b \propto T^4$$
$$e_b = \sigma T^4 \; [W/m^2]$$
$$= \sigma A T^4 \; [W/m^2]$$

where, σ = Stefan Boltzman Constant
$= 5.67 \times 10^{-8}$ W/m^{2}K^4.

Problems

Prob1

* The inner surface of a brick-wall is at 42°C & the outer surface is at 22°C. Calculate the rate of heat transfer, if the wall is 3m × 6m in cross section. it is 250mm thick & thermal conductivity of the wall is 0.55 W/mK.

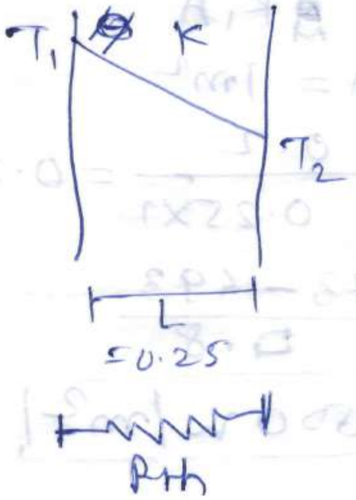
→ Given data $T_1 = 42°C = 42 + 273 = 315\,K$

$T_2 = 22°C = 22 + 273 = 295\,K$

cross-sectional area, $A = 3 \times 6 = 18\,m^2$

$L = 250\,mm = 0.25\,m$

$k = 0.55\,W/mK.$



Heat transfer $Q = \dfrac{T_1 - T_2}{R_{th}}$

Here $R_{th} = \dfrac{L}{KA}$

$= \dfrac{0.25}{0.55 \times 18} = 0.056$

$\therefore Q = \dfrac{315 - 295}{0.056}$

$\boxed{Q = 792\ \text{Watt}}$

* The inside & outside surface of furnace wall of 20cm thickness & 0.25 W/m°C thermal conductivity are at temperatures, 1100°C & 220°C respectively. Estimate the reduction in heat loss by adding 15cm thickness of insulating material on the outside surface having thermal conductivity 0.06 W/m°C. Assume the inside surface of wall to remain at 1100°C & temperature of insulating face at 20°C.

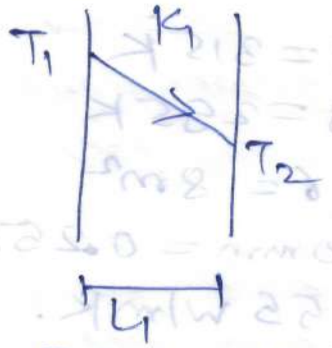
data given → $L_1 = 20cm = 0.2m$ $K_1 = 0.25 W/m^0C$

$L_2 = 15cm = 0.15m$ $K_2 = 0.06 W/m^0C$

$T_1 = 1100^0C = 1100 + 273 = \underline{1373^0K}$ $T_2 = 220^0C = 220 + 273 = \underline{493K}$

$T_3 = 20^0C = 20 + 273 = \underline{293^0K}$

Case I → Heat transfer without insulation.



Brickwall

$$\frac{Q}{A} = \frac{T_1 - T_2}{R_{th}}$$

Here $R_{th} = \frac{L_1}{K_1 A}$

assume $A = 1m^2$

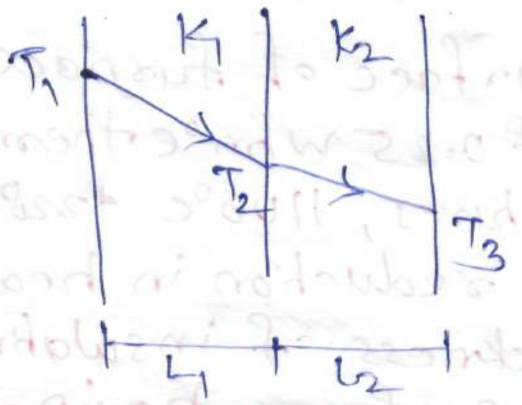
$$R_{th} = \frac{0.2}{0.25 \times 1} = 0.8$$

electrical analogy

$$\therefore Q = \frac{1373 - 493}{0.8}$$

$$\boxed{Q = 1100 W/m^2}$$

case-II → Heat transfer with insulation



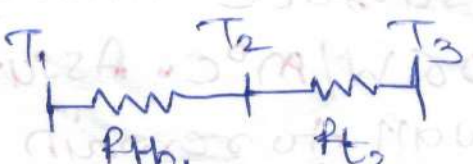
$$Q = \frac{T_1 - T_3}{R_{th}}$$

Here $R_{th} = R_{th_1} + R_{th_2}$

$$= \frac{L_1}{AK_1} + \frac{L_2}{AK_2}$$

$$= \frac{0.2}{0.25 \times 1} + \frac{0.15}{0.06 \times 1}$$

$$\boxed{R_{th} = 3.3}$$



Electrical analogy

$$\therefore Q = \frac{1373 - 293}{3.3} = 327.27 W/m^2$$

Reduction in heat loss $= 1100 - 327.27$
$= 772.73\ W/m^2$

Q.3 In problem (1) Find, temperature at a distance of 10 cm from hot surface.

→ Intermidiate temperature at a distance of 10 cm $\Rightarrow Q = \dfrac{T_1 - T_L}{L/KA}$.

Here, $l = 10$ cm

$$\therefore \quad Q = \frac{T_1 - T_L}{L/KA}$$

$$792 = \frac{315 - T_L}{\frac{0.1}{0.55 \times 8}}$$

$$\therefore \quad \frac{792 \times 0.1}{8 \times 0.55} = 315 - T_L$$

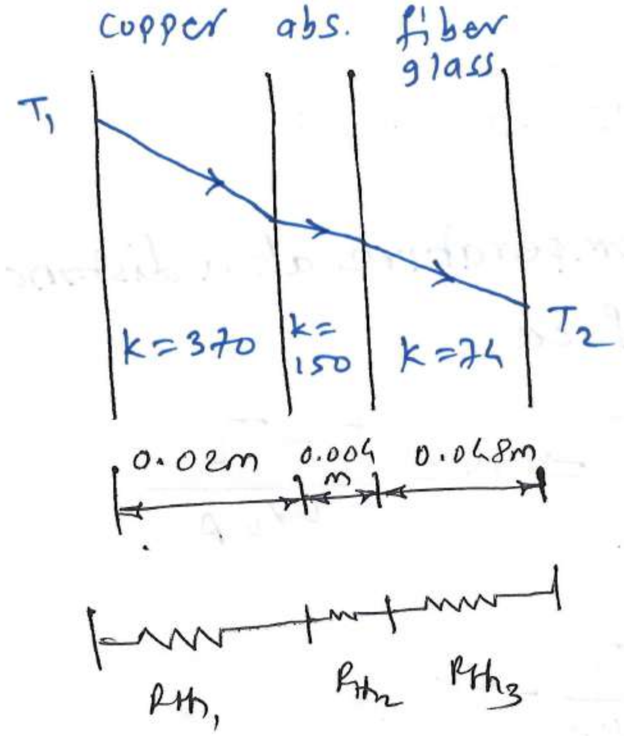
$$\therefore \quad 18 = 315 - T_L$$

$$\boxed{T_L = 297°c}$$

$$T_L = 297 - 273$$

$$\boxed{T_L = 24°c}$$

Q.4] A Composite wall is formed of 2cm copper plate, 4mm layer of asbestos & 4.8 cm of fibre glass. The wall is subjected to temperature difference of 400°c. Considering heat flow in one direction, from surface to surface. Calculate the heat flow per m^2 of wall. Take Conducting values are follows $K_{copper} = 370\ W/m°c$, $K_{ab} = 150\ W/m°c$, $K_{fglass} = 74\ W/m°c$.



electrical analogy

Heat transfer per m^2 of wall,

$$\frac{Q}{A} = \frac{T_1 - T_2}{R_{th_1} + R_{th_2} + R_{th_3}}$$

$$= \frac{400}{\frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3}}$$

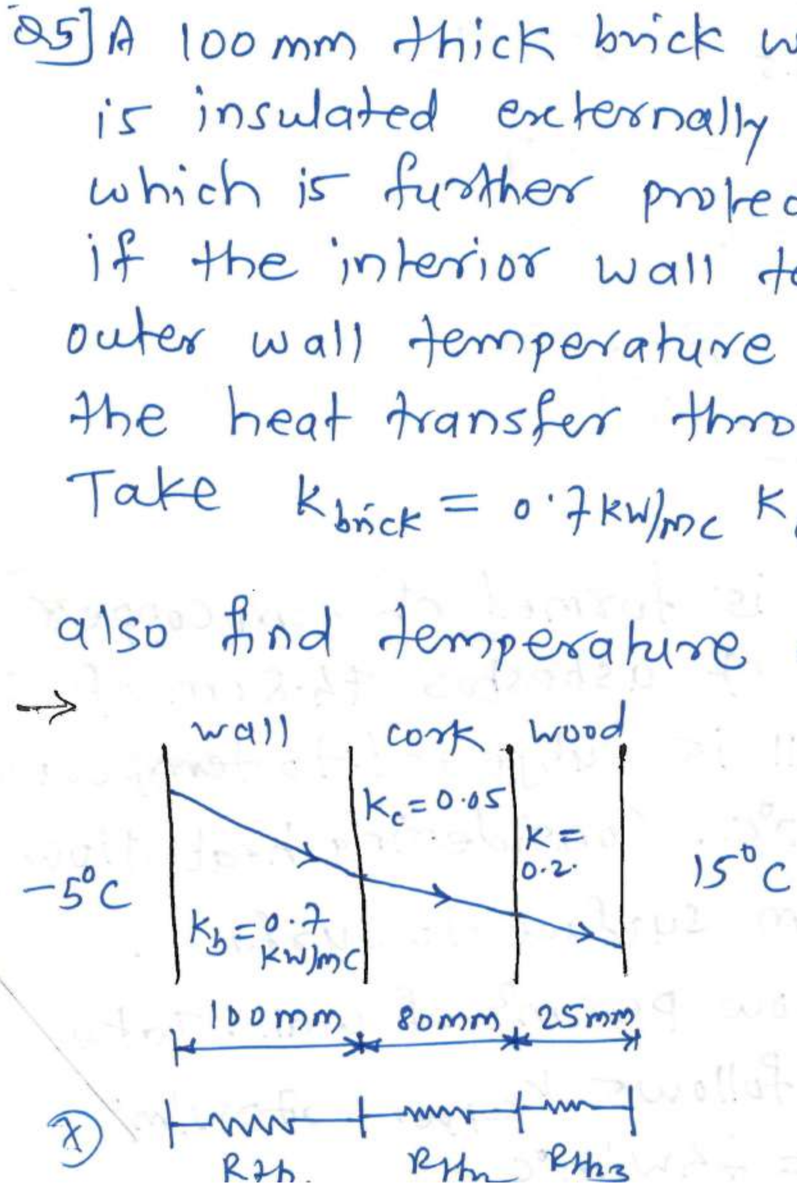
$$= \frac{400}{\frac{0.02}{370} + \frac{0.004}{150} + \frac{0.048}{74}}$$

$$\boxed{\frac{Q}{A} = 548418.97 \ W/m^2}$$

Q5] A 100 mm thick brick wall measuring 5m×3m is insulated externally by cork 80mm thick which is further protected by wood 25mm thick if the interior wall temperature is $-5°C$ & outer wall temperature is 15°C. determine the heat transfer through the wall per hour. Take $K_{brick} = 0.7 \ KW/mC$ $K_{cork} = 0.05 \ KW/mC$ $K_{wood} = 0.20 \ KW/mK$

also find temperature at inner surface.

→



wall area [A] = 5×3 = 15 m^2

temp. difference [dT] = ~~[illegible]~~ = 15 − [−5] = 20 °C

Thermal Resistance $[R_{th}] = R_{th_1} + R_{th_2} + R_{th_3}$

$$R_{th} = \frac{L_1}{K_1 A} + \frac{L_2}{K_2 A} + \frac{L_3}{K_3 A}$$

$$= \frac{0.1}{0.7 \times 15} + \frac{0.08}{0.05 \times 15} + \frac{0.025}{0.20 \times 15}$$

$$= 0.00952 + 0.10667 + 0.00833$$

$$= 0.12452 \text{ K/W}$$

Now, heat transfer

$$Q = \frac{dT}{R_{th}}$$

$$= \frac{20}{0.12452}$$

$$= 160.62 \text{ W } [J/sec]$$

Heat transfer in 1 hour

$$Q_{hour} = 160.62 \times 3600 \text{ [sec]}$$

$$= 578232 \text{ Joules}$$

$$\boxed{Q_{hour} = 578.232 \text{ kJ}}$$

Temperature at inner surface,

$$Q = \frac{T_{interface} - T_{interior}}{R_{brick}}$$

$$160.62 = \frac{T_{interface} - [-5]}{0.00952}$$

$$\therefore T_{interface} = [160.62 \times 0.00952] - 5$$

$$\simeq -3.47°C$$

4.2 Heat Exchanger

It is a device, which provides the surface area necessary to transfer of heat energy from one fluid to another fluid.

★ Classification

① According to method of Heat exchange process:-

A] Direct contact type B] Indirect contact type

2] According to direction of fluid flow:-

i] Parallel flow ii] Counter flow, iii] cross flow

3] According to design & constructional:-

i] concentric tubes 2] shell & tube 3] multiple shell & tube pass

1] Direct contact type HX:→

Heat exchange takes place by direct mixing of hot & cold fluids & transfer of heat & mass takes place simultaneously.

eg. jet condenser, cooling towers.

2] Indirect type HX:→

Heat transfer between two fluids is carried out by transmission through wall, which seperates the two fluids.

two types → Recuperators
→ Regenerator

1] Recuperators:-
In which, two fluids are seperated by wall.
eg. a] tube in tube type
b] shell & tube type
c] cross flow type.

a] tube in tube type:→
Consists of two concentric tubes of same length.
one fluid flows through the inner tube & other fluid flows through the annular space between the inner & outer tubes.
Classified as, 1] parallel flow type
2] counter flow type.

1] parallel flow type:→
Both fluid flows in same direction

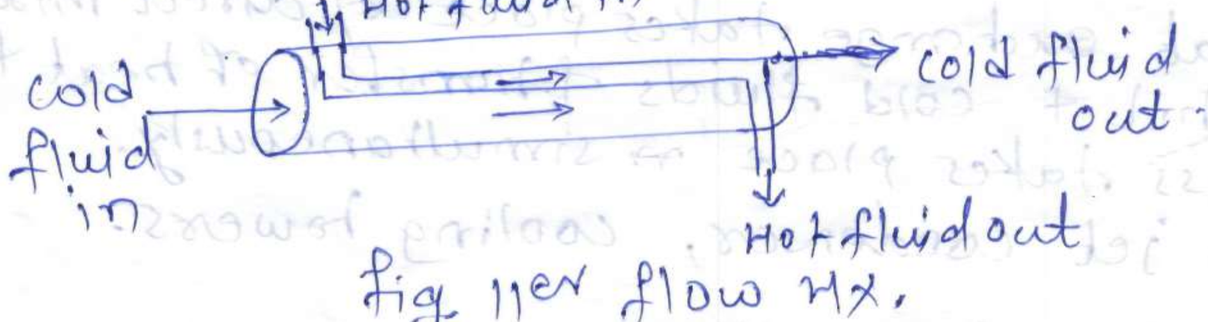


fig. 11er flow Hx.

2] Counter flow Hx:→
Both fluid flows in opposite direction

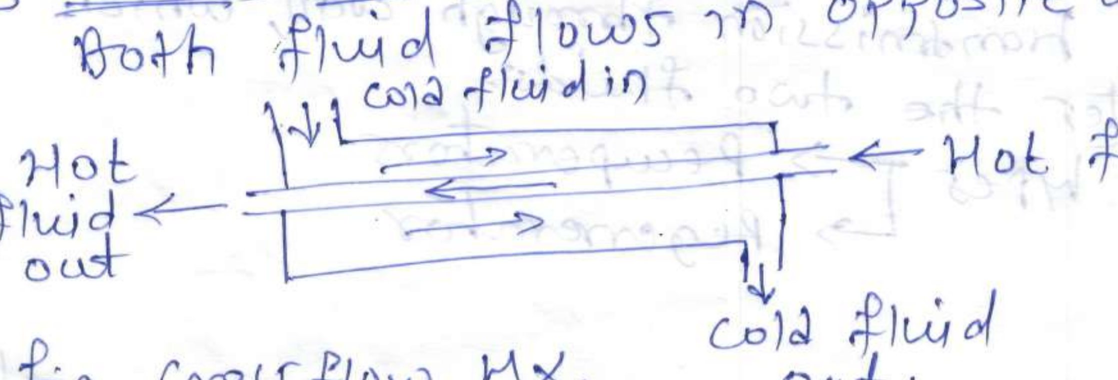


fig. cross flow Hx.

2] shell & tube type:-

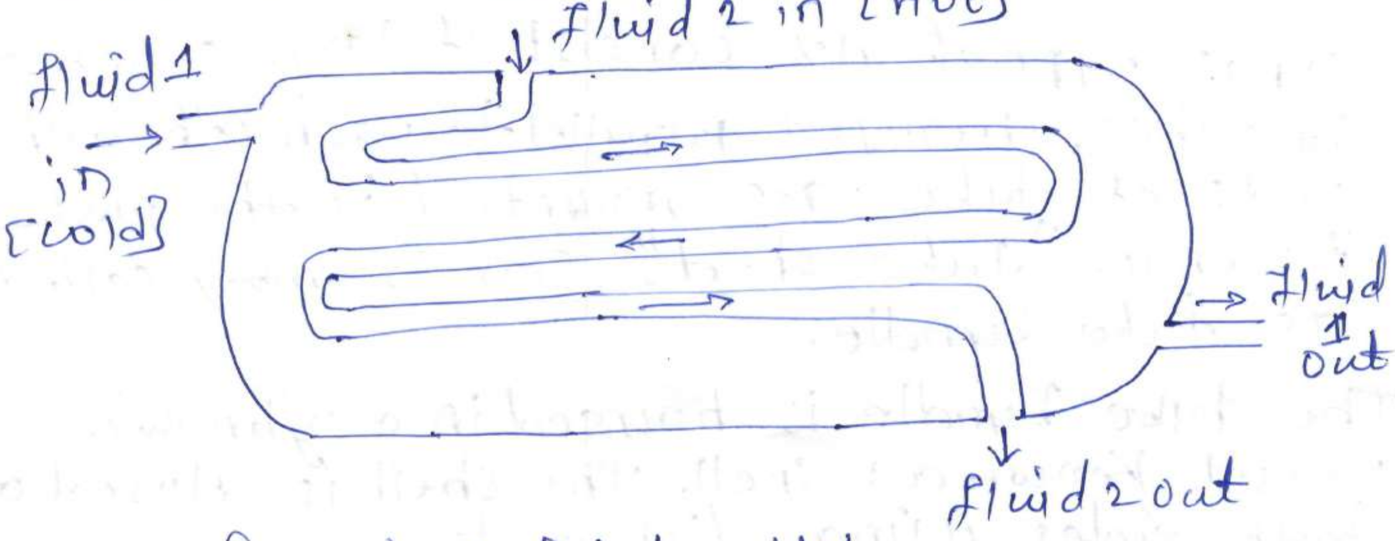


fig. shell & tube HX.

In this type of HX, one of the fluid flows through Bundle of tubes enclosed by shell. & other fluid enters the shell & flows over the surface of tubes.
Transfer of Heat takes place between these two fluids across the tube walls from inlet to outlet.

3] cross flow HX:->
The direction of flow of both fluids is at right angle to each other.
eg. car radiator, cooling unit of Refrigerator

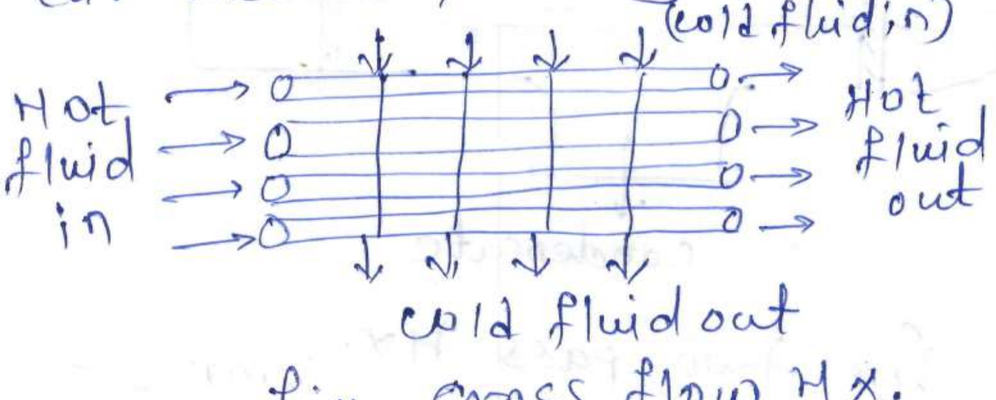


fig. cross flow HX.

2] Multipass Heat exchanger :->

This type of HX consist of large Number of tubes, arranged parallel to each other. the ends of tubes are mounted in the plate known as "tube sheet". This assembly called as tube bundle.

The tube bundle is housed in a cylindrical vessel known as shell. The shell is closed on both sides using dish ends.

Following figure shows cross-section of HX with two tube pass & one shell pass.

One fluid enters the dish on one side & flow through the tubes. The other fluid enters the shell & flows over the tubes. The Heat transfer is taken place across the tube walls.

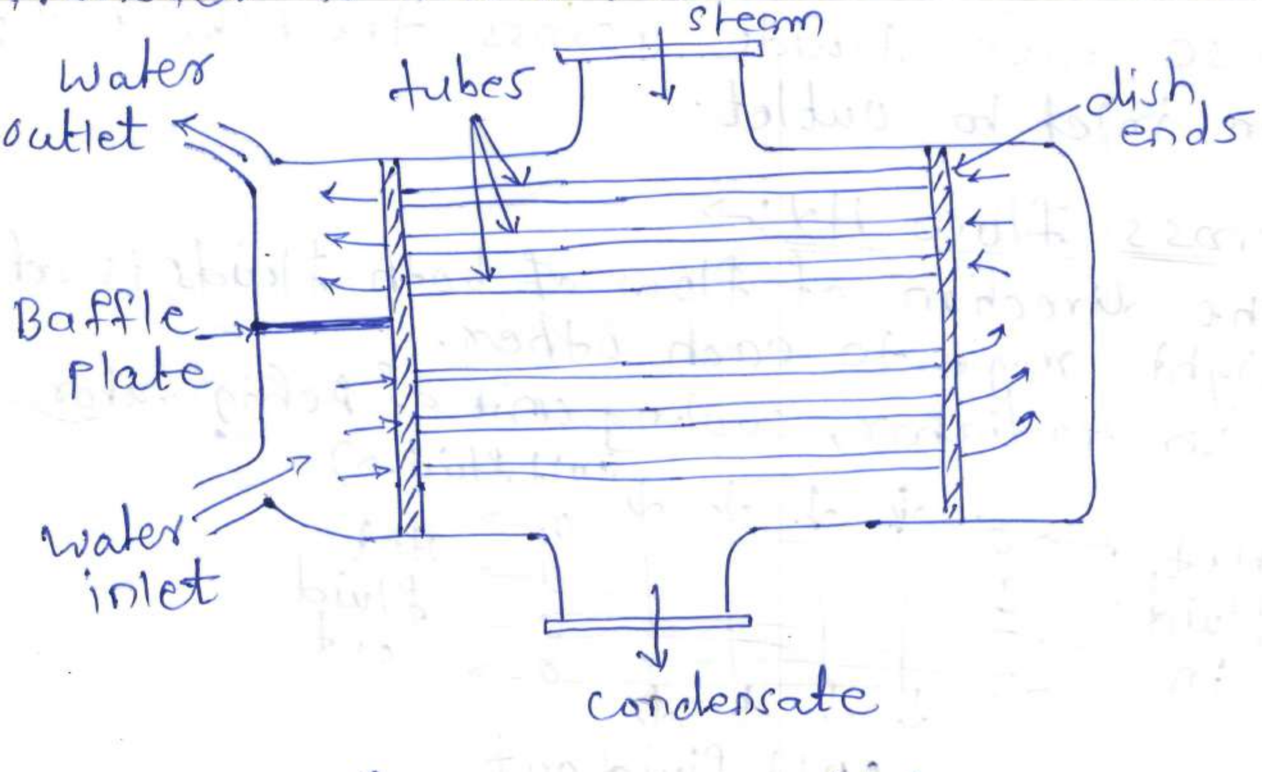


fig. two pass HX.

Imp

application of HX :->

1] Dairy industry.
2] food industry.
3] Refrigeration & air conditioning
4] steam & gas turbine power plant.

Imp

material used.

1] copper, brasses stainless steel. Aluminium bronze.