Tutorial No. 1

1. Heat flux through a wood slab 50 mm thick, whose inner and outer surface temperatures are 40°C and 20°C respectively, has been determined to be 40 W/m^2. What is the thermal conductivity of the wood slab?

① Data: $L = 50$ mm, $T_1 = 40°C$, $T_2 = 20°C$, $q = 40\ W/m^2$

→ To find: $k = ?$ W/mk.

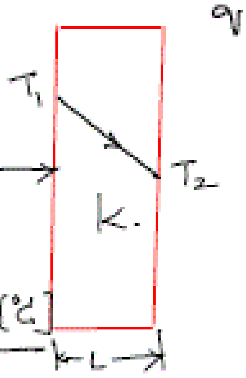
From fourier eqn we have $\quad q = \frac{Q}{A}$

$$q = -k\frac{dT}{dx} \rightarrow ①$$

(Good) ✓

$$q = k\frac{(T_1 - T_2)}{L}$$

$$Q = kA\frac{(T_1 - T_2)}{L} \xrightarrow{q}$$



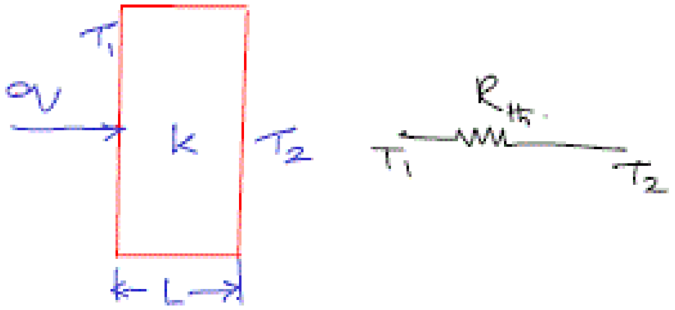
$$40\left[W/m^2\right] = \frac{k\left[W/m\text{-}°C\right](40-20)[°C]}{50\times10^{-3}[m]}$$

$$\therefore k = 0.1\left[W/m\text{-}°C \text{ (or) } W/m\text{-}K\right].$$

(Best) Known:- $L = 50$ mm, $T_1 = 40°C$, $T_2 = 20°C$; $q = 40\ W/m^2$ $\uparrow \left(\frac{Q}{A}\right)$

To find:. Thermal conductivity 'k'

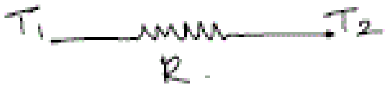
Schematic or figure (or) Sketch.



Assumptions:

Steady state, 1-D, constant 'k'

Analysis:- Thermal resistance circuit.



$$R = \frac{L}{kA_c} \quad \text{(1-D plane wall)}$$

From fourier law, we have.

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

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

$$q = k.\frac{(T_1 - T_2)}{L.} \quad \left[\text{Expression for 1-D plane wall}\right].$$

$$40\left[W/m^2\right] = \frac{k\left[W/m^\circ C\right]\,(40-20)\left[^\circ C\right]}{50\times10^{-3}\,[m]}$$

$$k = 0.1\left[W/m^\circ C\right]$$

Comments: The thermal conductivity of the material is found to be 0.1 W/m°C, indicates that the material is not good conductor of heat.

—— x ——

2. A concrete wall, which has a surface area of 20 m^2 and thickness 30 cm, separates conditioned room air from ambient air. The temperature of the inner surface of the wall is 25°C and the thermal conductivity of the wall is 1.5 W/(m-K). Determine the heat loss through the wall for ambient temperature varying from −15°C to 38°C which correspond to winter and summer conditions and display your results graphically.

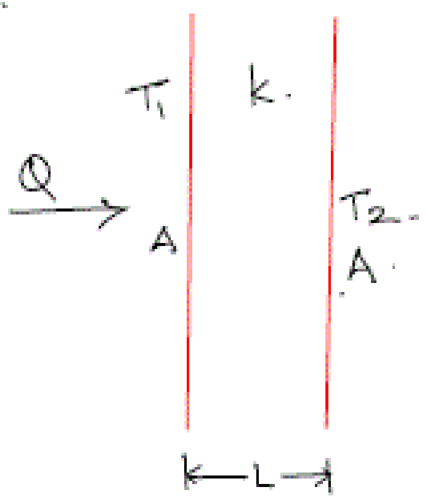
② Known: $A = 20\,m^2$; $L = 30\,cm = 0.3\,m$; $T_1 = 25°C$, $k = 1.5\,W/m\text{-}K$.

To find :- Heat exchanged Q' for T_2 in the range from −15°C to 38°C,

Assumptions:

① Steady state heat transfer.
② 1-D heat conduction.
③ Thermal conductivity 'k' remains same. (isotropic).

Sketch:



Resistance circuit

$$R = \frac{L}{kA}.$$

Analysis:-

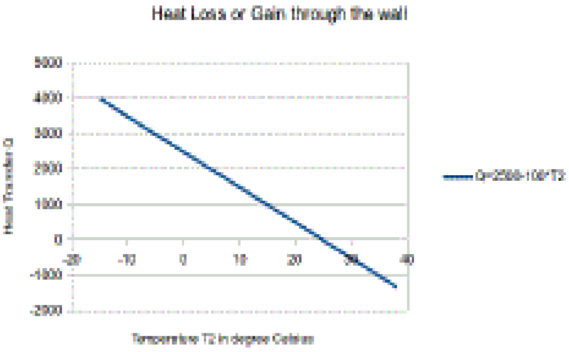
Heat transfer through the plane wall is:

$$Q = \frac{k.A\,(T_1 - T_2)}{L}$$

$$Q[W] = \frac{1.5\,[W/m\text{-}K]\;20\,[m^2]\;(25 - T_2)\,[°C]}{0.3\,[m]}$$

$$Q = 2500 - 100\,T_2 \longrightarrow ①$$

For temperature 'T_2' in steps of 2°C [−15°C to 38°C]



Comments:- Heat is transferred to the room @ higher temperature & as temp is decreased. heat flows out of the room (to ambient)

3. What is the thickness required of a masonry wall having a thermal conductivity of 0.75 W/(m-K), if the heat transfer rate is to be 80% of the rate through another wall having thermal conductivity of 0.25 W/m-K and a thickness of 100 mm? Both walls are subjected to the same temperature difference.

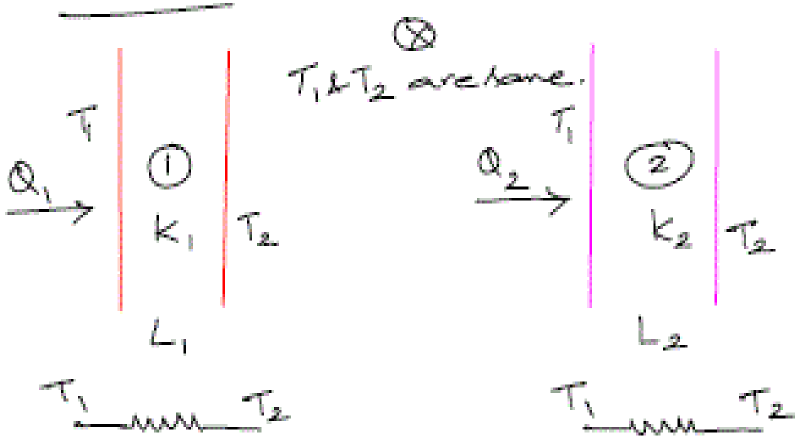
③ Known:→ $K_1 = 0.75\ W/m\text{-}K$; $Q_1 = 0.8 Q_2$; $K_2 = 0.25\ W/m$

$L_2 = 10mm$; T_1 & T_2 are same.

To find:→ Wall thickness L_1

Assumption: SS, 1-D, A = constant.

Schematic:



$R_1 = \frac{L_1}{K_1 A}$ $\qquad$ $R_2 = \frac{L_2}{K_2 A}$

$Q_1 = \frac{T_1 - T_2}{\frac{L_1}{K_1 A}}$ $\qquad$ $Q_2 = \frac{T_1 - T_2}{\frac{L_2}{K_2 A}}$.

$$(T_1 - T_2 = Q_1 \cdot \frac{L_1}{k_1 A} \rightarrow ① \qquad T_1 - T_2 = Q_2 \cdot \frac{L_2}{k_2 A} \rightarrow ②$$

$$① = ②$$

$$Q_1 \cdot \frac{L_1}{k_1} = Q_2 \cdot \frac{L_2}{k_2}$$

$$L_1 = \frac{Q_2 . L_2}{k_2} \times \frac{k_1}{Q_1}$$

$$= \frac{Q_2 \, L_2}{k_2} \times \frac{k_1}{0.8 \, Q_2}$$

$$= \frac{L_2}{k_2} \times \frac{k_1}{0.8}$$

$$L_1 = \frac{0.1 \, [m]}{0.25 \, [W/m\text{-}K]} \times \frac{0.75 \, [W/m\text{-}K]}{0.8}$$

$$L_1 = 0.375 \, m.$$

Comments:- The thickness of wall is 375mm, which is more than the other wall for the lesser heat transfer.

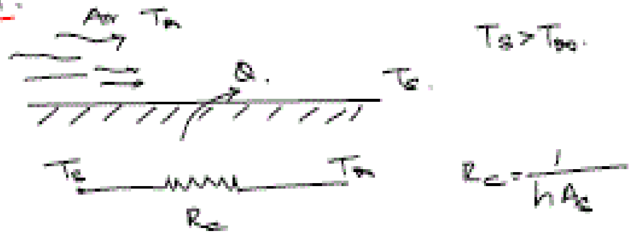
4. A large surface at $50°C$ is exposed to air at $20°C$. If the heat transfer coefficient between the surface and the air is $15 \; W/(m^2 - K)$, determine the heat transferred from $5 \; m^2$ of the surface area in 7 hours.

④ Known: $T_s = 50°C$; $T_\infty = 20°C$ $h = 15 W/m^2 k$
$A_s = 5 m^2$ $t = 7$ hours.

To find :- Q in time of 7 hours.

Assumptions:- Steady state, negligible radiation, constant properties

Sketch:



$R_c = \frac{1}{hA_c}$

Analysis:- From the newton's law of cooling

$$Q = h.A(T_s - T_\infty)$$

$$Q[W] = 15[W/m^2\text{-}K] \times 5[m^2]\,[50-20]^\circ C$$

$$Q = 2250\,(W)$$

Total heat transfer for seven hours is given by;

$$Q_{total} = 2250 \times 7 \times 3600$$

$$= 56.7\ MJ.$$

— × —

5. A 25 cm diameter sphere at 120°C is suspended in air at 20°C. If the convective heat transfer coefficient between the surface and air is 15 $W/(m^2 - K)$, determine the heat loss from the sphere.

⑤ Known:→ $d = 25cm$; $T_s = 120^\circ C$; $T_\infty = 20^\circ C$

$h = 15W/m^2K$;

To find:→ Q.

$$Q = hA_s(T_s - T_\infty) = 15[W/m^2K] \times 4\pi\left(\frac{0.25}{2}\right)^2(120-20)$$

$$Q = 294.52\ W.$$

— × —

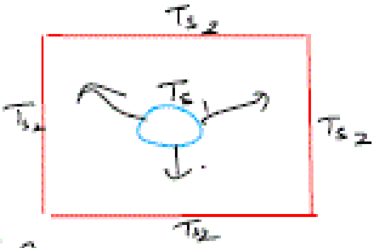
6. A sphere 10 cm in diameter is suspended inside a large evacuated chamber whose walls are kept at 300 K. If the surface of the sphere is black and maintained at 500 K what would be the radiation heat loss from the sphere to the walls of the chamber?. What would be the heat loss if the surface of the sphere has an emissivity of 0.8?

⑥ Known:- $d = 10cm$; $T_{s_2} = 300K$ $T_{s_1} = 500K$

$\epsilon = 0.8$.

To find:- ① $Q_{black\ body}$ ② $Q_{grey\ body}$.

Schematic:



Assumptions: S.S, Constant properties $\sigma = 5.67\times10^{-8}\ \frac{W}{mK^4}$

Area of the sphere $A_s = 4\pi r^2$
$= 4\pi\left(\frac{0.1}{2}\right)^2$

$A_s = 0.0314\ m^2$

Case 1: → Sphere is black body.

$$Q_{blackbody} = \overset{\checkmark}{\sigma} . A_s \left(T_{s_1}^4 - T_{s_2}^4\right) \checkmark$$

$$= 5.67\times10^{-8} \times 0.0314 \left(500^4 - 300^4\right)$$

$$Q_b = 96.85\ W.$$

Case 2:- Sphere is grey body.

$$Q_{grey} = \sigma . \epsilon A_s \left(T_{s_1}^4 - T_{s_2}^4\right)$$

$$= \epsilon . Q_b .$$

$$= 0.8 \times 96.85$$

$$Q_g . = 77.48\ W.$$

Comments:- $Q_g < Q_b$; as grey body emits less heat compared to a black body for the same temperature difference.

7. Asbestos layer of 10mm thickness with k=0.116 W/mK is used as insulation over a boiler wall. Consider an area of 0.5m² and find out the rate of heat flow as well as the heat flux over this area if the temperatures on either side of the insulation are 300°C and 30°C.

In order to study the effect of insulation, if asbestos is replaced by glasswool with k=0.038 W/mK, what amount of heat can flow through the same area and temperature difference.

Also tabulate the values of heat flux for both materials if the higher surface temperature of 300°C is varied from 300°C to 350°C, say in steps of 10°C.

Case 1:–

7. Known:→ $L_1 = 10mm$; $k_1 = 0.116\ W/_{m-K}$; $A = 0.5 m^2$

$T_1 = 300°C$ $T_2 = 30°C$

Case 2: k_1 is replaced by $k_2 = 0.038\ W/_{m-K}$

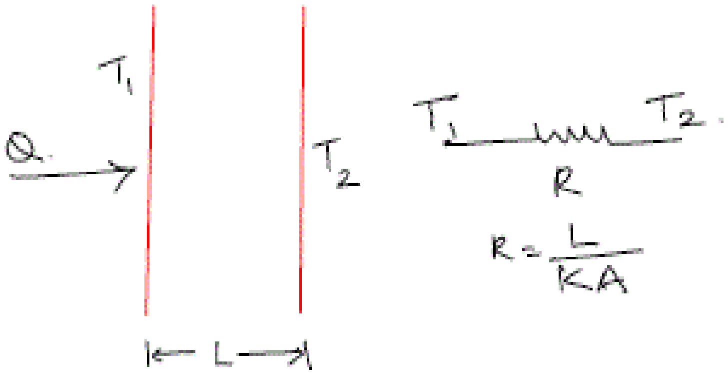
$k_2 < k_1$

wrt

To find: Q_1, Q_2 & Tabulate values of Q_1, Q_2, for T_1 varying from 300°C to 350°C, ∝10°C

Assumptions:- S.S, 1-D, constant properties, A=∞

Schematic:



Case 1: Asbestos

$$Q_1 = k_1 A \left[\frac{T_1 - T_2}{L}\right]$$

$$Q_1 = 0.116 \times 0.5 \times \frac{[300 - 30]}{0.01}$$

$Q_1 = 1566\ W.$

Case 2:- Glass wool

$$Q_2 = k_2 A \left[\frac{T_1 - T_2}{L}\right]$$

$$Q_2 = 0.038 \times 0.5 \left[\frac{300 - 30}{0.01}\right]$$

$$Q_2 = 513 \text{ W}$$

Comments:- For the same temperature difference, heat transfer through glass wool is less than asbestos; because of low thermal conductivity of glass wool.

Tabulated values:-

T1	T2	Q1=k1*A(T1-T2)/L	Q2=k2*A(T1-T2)/L
300	30	1566	513
310	30	1624	532
320	30	1682	551
330	30	1740	570
340	30	1798	589
350	30	1856	608

Q_1 & Q_2 ↑ with increase in source temp 'T_1'