HEAT TRANSFER

Heat can be transferred by three methods:

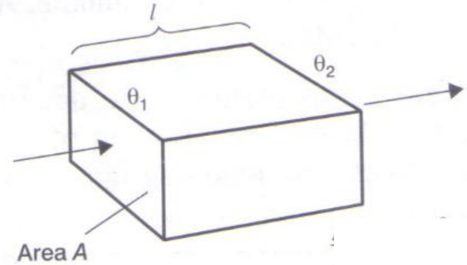
- Conduction
- Convection
- Radiation

Thermal Conduction

Conduction is the process by which heat flows from hotter regions of a substance to the colder regions without any movement of the substance itself.

Thermal Conductivity (*k*)

The thermal conductivity (*k*) of a material is the measure of ease of which heat passes through it from hotter region to cooler region.



It is defined by equations for the rate of transfer of

$$\frac{\Delta Q}{\Delta t} = kA\left(\frac{\theta_1 - \theta_2}{l}\right)$$

Units: *J/s* or Watts (*W*)

where $\frac{\theta_1 - \theta_2}{l}$ is the temperature gradient (units: *K/m*)

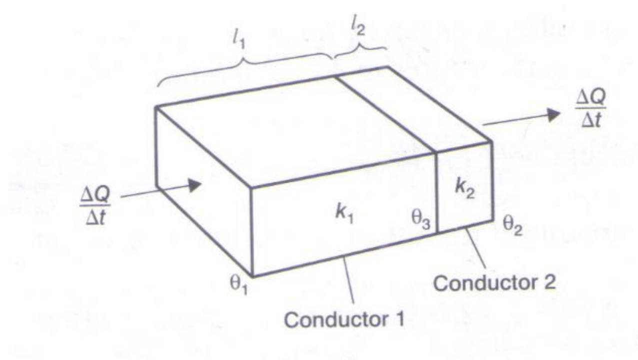
k is the thermal conductivity (units: $Wm^{-1}K^{-1}$)

Definition of (*k*)

The coefficient of thermal conductivity of material is the rate of flow of heat per unit area per unit temperature gradient when the heat flow is at right angles to the faces of a thin parallel-sided slab of material under steady state condition.

(***N.B*** A substance is said to be in a steady state when the temperatures at all points in it are steady)

Thermal Conductors in Series (Composite Materials)



Since no heat is loss in the sides, we can say that

$$\frac{\Delta Q}{\Delta t} = k_1 A \left(\frac{\theta_1 - \theta_3}{l_1}\right)$$

Which is the same as

$$\frac{\Delta Q}{\Delta t} = k_2 A \left(\frac{\theta_3 - \theta_2}{l_2}\right)$$

Thermal Resistance

We can calculate the thermal resistance by using the formula

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

where L is the length , A is the area and k is the thermal conductivity

Hence the total resistance in two conductors in series can be calculated by using

$$\boldsymbol{R_T = R_1 + R_2}$$

where

$$R_1 = \frac{L_1}{k_1 A_1}$$

$$R_2 = \frac{L_2}{k_2 A_2}$$

Example 1

Two perfectly lagged metal bar, X and Y are arranged:

a) In series
b) In parallel

When the bars are in series the ‘hot’ end of X is maintained at 90 ^{o}C and the ‘cold’ end of the bar Y at 30 ^{o}C. When the bars are in parallel the ‘hot’ end of end of each is maintained at 90 ^{o}C and the ‘cold’ end of each is maintained at 30 ^{o}C. Calculate the ratio of the total rate of flow of heat in the parallel arrangement to that in the series arrangement. The length of each bar is, L, and the cross sectional area of is A. The thermal conductivity of X is 400 $Wm^{-1}K^{-1}$ ant that of Y is 200 $Wm^{-1}K^{-1}$.

Example 2

One room in a house has a floor made entirely of concrete which 200mm thick. The lower surface of concrete, in contact with the ground, has a temperature of 10 ^{o}C and the upper surfaces in contact with the living area, has a temperature of 15 ^{o}C. The floor is square and with sides 10m by 10m.

a) Calculate the rate at which thermal energy is conducted through the concrete. Assume the thermal conductivity of concrete is 0.750 $Wm^{-1}K^{-1}$.

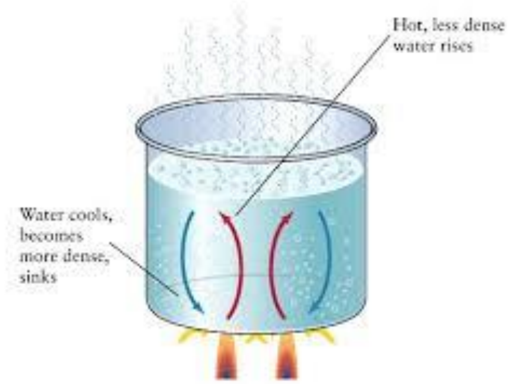
The house owner decides to cover the concrete with carpet of thickness 15.0 mm. Calculate:

b) The temperature at the carpet/ concrete interface
c) The rate at which the thermal energy through the two layers.

Assume that the carpet has a thermal conductivity of 0.60 $Wm^{-1}K^{-1}$. Also assume that the temperature of the upper surface of the carpet is 15 ^{o}C and the temperature of the lower surface of the concrete remains at 10 ^{o}C.

Thermal Convection

This is the transfer of energy by the movement of fluids as a result in the change in densities.



The liquid closest to the flame gains the most energy. Increase in heat energy is realised as increase in kinetic energy (KE). An increase in KE gives rise to an increase in volume of the liquid which in turns leads to a decrease in density. Hence the less dense liquid rises and is replaced by the more dense liquid. This movement is repeated as heating continues and sets up convection currents.

Ocean Currents

There is a general drift of tropical ocean waters towards the north and south poles with a corresponding return flow from the poles to the equator. The pole flow begins as a surface current but overtime sinks to the bottom of the ocean. The heat energy is transported toward the poles by ocean currents. In the Western part of every ocean between the latitudes 5^o and 45^o there is a warm current which takes the thermal energy into the middle latitudes. The best known of these currents is the Gulf of Mexico through the North Atlantic to the edge of the Arctic Ocean.

Thermal Radiation

This is the electromagnetic radiation emitted by a body as a result of its temperature. The frequency of the radiation emitted depends on the temperature which the body possesses. The hotter the body, the higher the frequency of radiation which is emitted.

Radiation spans a continuous range of wavelengths and distribution depends on the temperature of the emitter. Temperatures below 100 ^oC emits energy within the infra-red range. Higher temperatures the energy is associated with the visible light and the ultra violet range. When thermal radiation is incident some may be reflected, transmitted and absorbed to produce a heating effect. Substances which transmit thermal radiation incident to it are said to be diathermanous. Substances which absorb thermal radiation are said to be adiathermanous.

(***N.B.*** absorption of electromagnetic radiation of any wavelength may produce a heating effect)

Prevost's Theory of Exchange

This law states that:

A body emits radiation at a rate which is determined by the nature of its surface temperature. The body also absorbs radiation at a rate which is determined by the nature of its surface and the temperature of the surroundings.

(***N.B.*** Good absorbers of radiation are also good emitters of radiation. Hence black surfaces are the best absorbers and emitters of heat, while silver surfaces are poor emitters and absorbers of heat)

A black body is defined as a body that absorbs ALL the radiation which is incident on it. A black body radiator is one which emits radiation which is characteristic of its temperature which doesn't depend on the nature of its surface.

Stefan's Law

This law states that:

The total energy radiated per unit time per unit surface of a black body is proportional to the fourth power of the temperature of the body expressed in Kelvin.

$$P = A\sigma T^4$$

where A is area (m^2)

T is temperature (K)

σ is Stefan's constant ($5.67\times10^{-8}\ Wm^{-2}K^{-4}$)

Stefan's Law applies to black objects. For non-black body objects, the role is modified as shown in the formula below:

$$E = \sum\sigma T^4$$

where $\sum$ indicates the total emissivity of the body. The emissivity value depends on the nature of the body and lies between 0 and 1.

U - Values

The U – Value of a structure is defined as the heat energy transferred per unit time through a unit area of the structure; when there is a unit temperature change across it.

$$Rate\ of\ transfer\ of\ heat = U\ A\Delta T$$

where U is the U-Value ($Wm^{-2}K^{-1}$)

A is the area of the surface (m^2)

ΔT is the temperature change across structure (K)

Examples of U – Values

Structure	U –Values ($Wm^{-2}K^{-1}$)
single brick wall	**3.3**
single window	**5.5**
double glazed window	**1.9**
tile roof	**2.0**

Review & Research: Vacuum Flasks and Solar Water Heaters

The use of heating and cooling systems to reduce the Caribbean's dependency on fossil fuels.