UIT-RGPV (Autonomous) Bhopal
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Unit: -IV

Lecture no.18

Basic concept of Heat transfer

1. Basic concept of Heat transfer

- What is heat transfer?
  Heat transfer is thermal energy in transit due to a temperature difference. In other words, heat transfer is to predict the energy transfer between material bodies.
  [*In the simplest of terms, the discipline of heat transfer is concerned with only two things: **temperature**, and the **flow of heat**. Temperature represents the amount of thermal energy available, whereas heat flow represents the movement of thermal energy from place to place.]*

- How Science of heat transfer explain:
  - How heat energy may be transfer?
  - Predict the rate at which the exchange will take place?
  - Different between thermodynamics and heat transfer ?

- Thermodynamics deal with system in equilibrium, it may used to predict of energy required to change a system from one equilibrium state to another. But it does not predict how fast a change will take place.

Table 1: Comparison between heat transfer and thermodynamics

HEAT TRANSFER	THERMODYNAMICS
• Heat transfer is a study which predicts the energy transfer which takes place between material bodies. • It is due to the temperature difference • Heat transfer explains how heat energy may be transferred. • It also predicts the rate at which the exchange will take place under certain condition.	• Thermodynamics deals with systems in equilibrium. • Thermodynamics may used to predict the amount of energy required to change a system from one equilibrium state to another. • Thermodynamics may not used to predict how fast a change will take place since the system is not in equilibrium during the process.

Three modes of heat transfer are:
(1) Conduction
(2) Convection
(3) Radiation

2. Conduction heat transfer

2. Conduction Heat Transfer

- Energy transfer from high temperature region to low temperature region. We said that the energy is transferred by conduction. And, the heat transfer rate per unit area is proportional to the normal temperature gradient.

$$q/A \sim dT/dx$$

where,
q/A = heat transfer rate (W/m^2)
dT/dx = temperature gradient in the direction of the heat flow

When proportionality constant is inserted,

$$q = - kA\, dT/dx \qquad (1)$$

- The positive constant k = thermal conductivity of the material. The minus (-) sign is inserted so that the second principle of thermodynamics will be satisfied i.e. heat must flow downhill on the temperature scale as indicated in Figure 1

Equation (1) is called Fourier's Law of heat conduction. Above is defining equation for the thermal conductivity and *k* has the unit of Watts per meter per Celsius degree (W/m.°C), which the heat flow is expressed in watts.

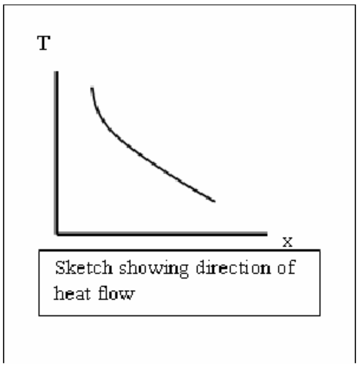

Figure1: Sketch showing direction of heat flow

Table 1: Lists typical values of the thermal conductivities of some metal (thermal conductivity at 300 K(W/m K)).

Metal	*k*
Copper, pure	396
Aluminium	238
Carbon steel, 1% C	42
Plastics	0.2 - 0.3
Air	0.026

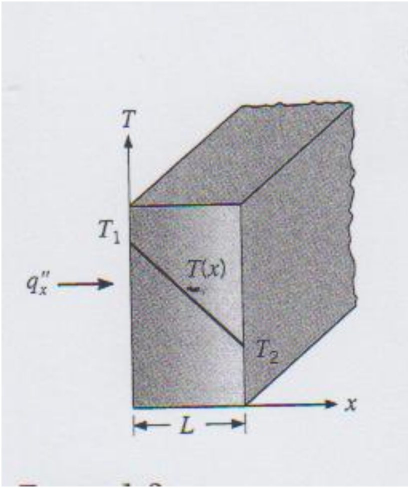

Figure 2: One –dimensional plane wall

- Consider the one-dimensional plane wall shown in Figure above, if the system in a steady state, i.e., if the temperature does not change with time, then only integrate Equation (1) and substitute the appropriate values.

$$\frac{q}{A}\int_{0}^{x} dx = \int_{T2}^{T1} kdT$$

- Where temperature at the left face (x=0) is uniform at T_1 and the temperature at right face is uniform at T_2. If k is independent of T, we obtain after integration :

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

- Under the steady state conditions, where the distribution is linear, the temperature gradient may be expressed as:

$$\frac{dT}{dx} = \frac{T_2 - T_1}{L}$$

- And the heat transfer rate:

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

or;

$$\frac{q}{A} = k\frac{T_1 - T_2}{L} = k\frac{\Delta T}{L}$$

- Since dT/dx = - q/k for the same q, if *k* is low (i.e: for an insulator), dT/dx will be large .i.e. there will be a large temperature difference across the wall, and if *k* is high (i.e. for a conductor), dT/dx will be small, or there will be a small temperature difference across the wall.

Example 1

One face of a copper plate 3 cm thick is maintained at 400 °C, and the other face maintained at 100 °C. How much heat is transferred through the plate? Given: k = 370 W/m.K.

From Fourier's Law,

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

Integrating gives

$$\frac{q}{A} = -k\frac{\Delta T}{\Delta x} = \frac{-(370)W/m.K(100-400)K}{3\times10^{-2}m}$$

$$q/A = 3.7\ MW/m^2$$

3. Convection Heat Transfer

It is well known that hot plate of metal will cool faster when placed in front of a fan than when exposed to still air. We say that, heat is convected away, and we call the process, convection heat transfer. The velocity at which the air blows over the hot plate obviously influence the heat transfer rate.

(a) Mechanism of convection

Consider the heated plate shown on Figure 3. Temperature of plate is T_w and temperature of the fluid is T_∞. The velocity of the flow will appear as shown in the figure.

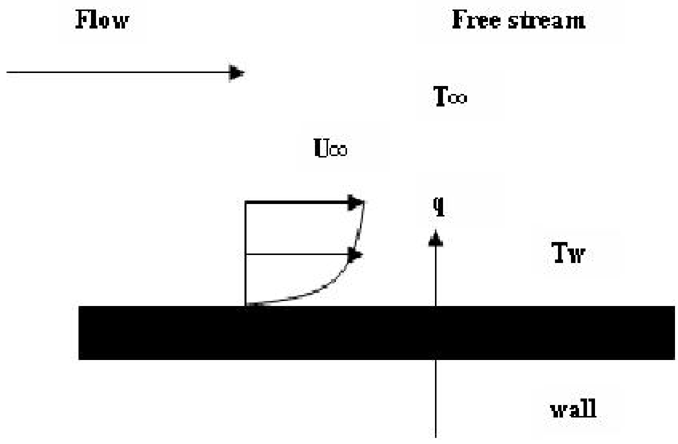

Figure 3: Convection heat transfer from a plate

- The velocity is being reduced to zero at the plate as a result of viscous action. Since the velocity of fluid layer at the wall will be zero, the heat must be transferred only by conduction. Thus we might compute the heat transfer, using:

  $$q = -kA\ (dT/dx)$$

  but with little changes. We use thermal conductivity of fluid and the fluid temperature gradient at the wall.The temperature gradient is dependent on the rate at which the fluid carries the heat away. High velocity produces a large temperature gradient. Thus, the temperature gradient at the wall depends on the flow field. To express the overall effect of convection, we use Newton's law of cooling:

  $$q = hA\ (T_w - T_\infty) \qquad (2)$$

  where,

  h = convection heat-transfer coefficient (heat-transfer coefficient = film conductance)
  h = watt per square meter per Celsius degree ($W/m^2\ .°C$) when the heat flow is in Watt.

- Heat-transfer rate is related to overall temperature difference between the wall and fluid and the surface area.

(b) Free and Forced Convection

If heated plate were exposed to ambient room air without an external source of motion, a movement of the air would be experienced as a result of the density gradients near the plate. We call this as free convection. When the mass motion of the fluid is caused by an external device like a pump, compressor, blower or fan, the process is called forced convection.