Chapter-8

Fundamentals of thermodynamics and heat transfer:

8.3. Heat transfer:

Heat is a common form of energy which is continuously being transferred from one body to another. In earlier time, during the development of concept of heat and temperature, people had only the concept of inequality for flow of heat. According to this concept, heat always flows from a body of higher temp. to a body of lower temp. Actually, heat always flows until there is difference in temp.

There are three different modes of transfer of heat. Transfer of heat due to actual motion of molecules in fluid (liquid and gas) is called convection, eg. boiling of water. Transfer of heat due to molecular vibrations in a solid is called conduction eg. heating of metal rod. Transfer of heat without support of any material medium is called radiation. eg. receiving heat from sun.

These modes of heat transfers are described as following:

① Conduction:

Conduction is the process of transfer of heat from one point to another point of a body carried out by means of collisions between rapidly vibrating atoms at hotter region and slowly vibrating atoms at colder region. There is no actual transfer of particles during conduction.

when one end of a solid is heated, atoms at hotter end vibrate with greater amplitude and have more K.E. than neighbouring atoms at colder part. The atoms at hotter region collide with and give up some energy to the neighbouring atoms in colder regions. Similar process continues between each set of neighbouring atoms up to next end. As a result transfer of heat takes place and previously cold end also gets heated. This method of transfer ~~s~~ of heat is called conduction.

(2) Convection:

Convection is the process of ~~heat~~ transfer of heat in fluids by means of actual motion of heated particles from higher temperature region to lower temp. region.

Heated particles carry heat and move from hot region to cold region but cold particles move in opposite direction. The current set up in the process is called convection current. This method is not possible in solid and vacuum. Heating of water, land breezes, sea breezes, wind etc. are some examples of convection.

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(3) Radiation:

Radiation is the process of transmission of heat from one point to another without need of any material medium. Radiation does not heat the medium through which heat energy passes.

In radiation, heat is transferred in the term of e.m. radiation (wave) and travel with speed of 3×10^{8} m/sec. in vacuum. Heat energy comming to the earth from the sun, and transmission of heat ~~area~~ around fire are the examples of radiation. Heat energy radiated by an object is called radiant energy or thermal energy.

(II) Statement and assumption of Fourier law of thermal conductivity:

The ability of anybody to conduct heat is measured in term of thermal conductivity. Therefore, Ability which measures the thermal conduction of material is called thermal conductivity. Thermal conductivity generally occurs in solids.

Statement of Fourier law of Thermal conductivity:

The Fourier law states that the rate of heat flow in solids is directly proportional to the cross-section area perpendicular to the flow axis and negative of temp. gradient over the length of the path of conduction.

According to Fourier's law, the rate of heat flow Q through a homogenous solid is directly proportion -al to the area A of the section at the right angles to the direction of heat flow, and to the temp. difference dT along the path of heat flow.

i.e. $Q = -KA\frac{dT}{dx}$ — (1)

where
Q = rate of heat transfer (watt)
K = Thermal Conductivity (W/m·K)
A = Area of cross-section (m^2)
dT = Change in temp. along the dirn. of heat flow
dx = Thickness of the object.

In the fourier heat conduction eqn. the -ve sign implies that heat is flowing from higher temp. to lower temp. therefore it is provided to compensate for the negative nature of the temp. gradient.

Assumption in fourier law of heat conduction:

Following are the assumptions of fourier law of heat conduction:

1. The thermal conductivity of the material is constant throughout the material.
2. There is no internal heat generation that occurs in the body.
3. The temp. gradient is considered at constant.
4. The heat flow is unidirectional and takes place under steady-state conditions.
5. The surfaces are isothermal.

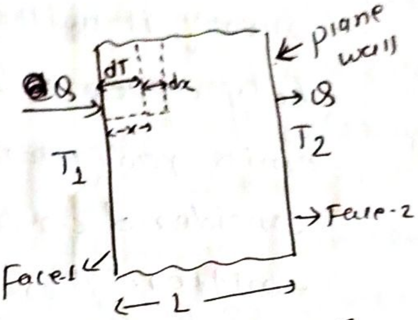
Temperature gradient

The rate of fall in temp. with distance along the dirn of heat flow is called the temp. gradient.

It is expressed as $-\frac{dT}{dx}$ and its unit is kelvin per meter (K/m). Here dT is the small change in temp. over a small distance dx and -ve sign indicates that temp. falls with distance.

One dim^n steady state heat conduction through plane wall

Consider parallel sided plane wall of thickness L and uniform cross-section area A, as shown in figure. Let K be the thermal conductivity of wall material through which heat is flowing only in x-direction. Let T_1 and T_2 are the temp. of higher temp. face-1 and lower temp. face-2. The small change of temp. dT when the particles conduct ~~the~~ very small distance dx.



[Fig: plane wall]

According to fourier law, the rate of heat transfer is given by

$$\frac{dQ}{dt} = -KA\frac{dT}{dx}$$

or $$\frac{dQ}{dt}dx = -KA\,dT \quad \text{--- (1)}$$

To obtain the rate of flow of heat through this whole wall is obtained by integrating eq^n (1), we get

$$\int_0^L \frac{dQ}{dt}dx = \int_{T_1}^{T_2} -KA\,dT$$

or $$\frac{dQ}{dt}\int_0^L dx = -KA\int_{T_1}^{T_2} dT$$

or $$\frac{dQ}{dt}[L-0] = -KA[T_2 - T_1]$$

or $$dQ/dt = \frac{KA(T_1 - T_2)}{L}$$

$$\Rightarrow \frac{dQ}{dt} = \frac{(T_1 - T_2)}{L/KA} \quad \text{--- (2)}$$

where $\frac{L}{KA}$ = Thermal resistance R_{th}

$$\therefore \frac{dQ}{dt} = \frac{T_1 - T_2}{R_{th}} \quad \text{--- (3)}$$

This eq^n (3) gives the rate of flow of heat through the wall. If R_{th} increases, $\frac{dQ}{dt}$ decreases and vice-versa.