A Study on Conduction Heat Transfer

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Abstract— Heat transfer is a way of energy exchange which takes place between a higher temperature object to that of a lower. This heat transfer happens in three different types, namely: conduction, convection and radiation. Conduction is a type of contact heat transfer in which when a temperature gradient exists, there is a flow of energy from higher potential to lower. Conduction heat transfer varies depending on the many factors such as material properties, temperature gradient, the phase of the material (solid. liquid or gas), distance, etc.

Key words: Conduction Heat Transfer, Lattice Vibrations, Fourier's Law, Thermal Conductivity

I. Introduction

Types of heat transfer:

- Conduction
- Convection
- Radiation

Heat transfer is the study of energy transfer that takes between two material bodies because of temperature difference. Heat transfer supplements the first and second Laws of thermodynamics by providing additional experimental rules used to establish energy transfer rates.

A. *Conduction Heat Transfer*

When a temperature gradient exists in a body (Fig.1), it is observed that there is a flow of energy from the high temperature region to low temperature region. This time dependent mode of transport of energy can be defined as conduction. It is also observed that the energy transferred by conduction and the heat transfer per unit area is proportional to the normal temperature gradient.

$$q_x/A \sim dt/dx$$

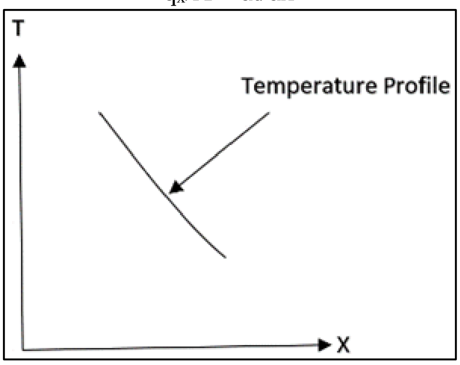


Fig. 1: Direction of Heat Flow

When the proportionality constant is considered

$$q_x = -kA\ dt/dx \qquad (1.1)$$

Where,

q_x is heat transfer ratz dt/dx is temperature gradient in the direction of heat flow k is a called thermal conductivity S.I Unit: Watts/m. °C (-vet symbol is inserted to satisfy the second law of thermodynamics)

Eq. 1.1 is called Fourier's law named after French physicist Joseph Fourier.

II. Heat Transfer Mechanisms in Conduction

In solids, heat transfer through conduction takes place by mainly two mechanisms:

- By Lattice Vibration

The molecules and atoms in the high temperature region are colliding with each other at faster rate and thus transferring heat to adjacent molecules due to impact.

- By Transportation of Free Electron

An energy flux is observed along the decreasing direction of a temperature gradient.

In gases, heat transfer is due to:

- Kinetic Energy

Kinetic energy at molecular level is observed to be a function of temperature as explained in the kinetic theory of gasses. These molecules due to high kinetic energy are in continuous random motion exchanging energy and momentum. When a molecule with high kinetic energy or at high temperature collides with a molecule with low kinetic energy and low temperature, energy is lost or gained by law of conservation of momentum.

In liquids the manner of heat transfer is similar to that of the gas. However, the atoms are more closely packed thus causing the intermolecular forces to come into the picture.

III. Thermal Conductivity

The magnitude of thermal conductivity 'k' for a given substance depends upon the microstructure of the material and temperature at a given instant. It is a tensor property, expressing anisotropy of the property. It indicates the amount of heat that flows through a unit area when the temperature gradient is unity. It can be defined as the measure of speed of heat transfer in a given material.

In solids the inter particle interaction is comparatively stronger and the alignment of particles in its lattice structure is more dense than compared to those of the fluids. This collective interaction of many particles is then interpreted as sound waves. These quantized sound waves act like weakly interacting quasi-particles called phonons. The scattering of electrons is directly dependent on the temperature. The higher the temperature the more is the scattering and visa-versa. Thus, it affects the conductivity.Fig.2 shows the relation between Thermal Conductivity and temperature.

An equation called Weidman-Franz Law [1.2] was derived which shows the electron and phonon contribution.

$$k = C3 + C4/T \qquad (1.2)$$

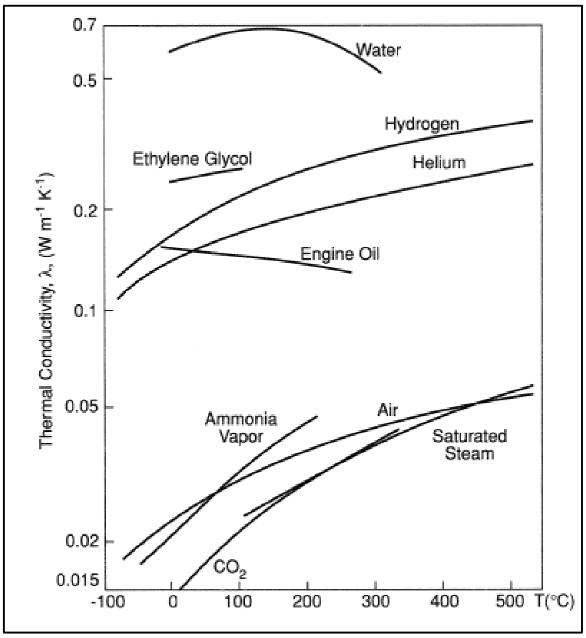
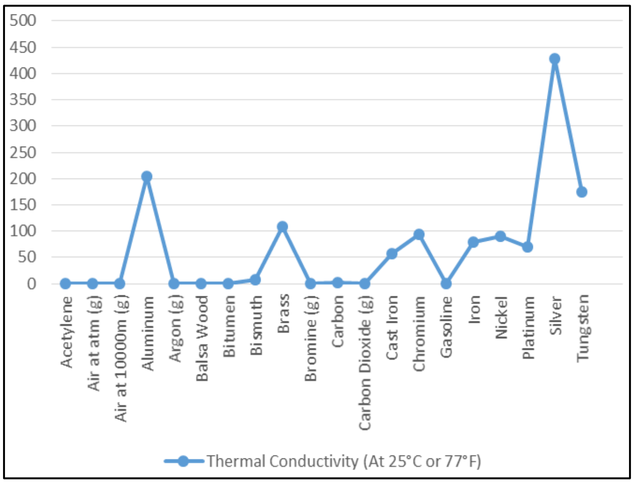


Fig. 2: Relationship between Thermal Conductivity and Temperature

Table 1 and the Graph 1 below show how the materials and their different microstructures affect the thermal conductivity.

Material	Thermal Conductivity (At 25°C or 77°F) (W/m-k)
Acetylene	0.018
Air at tam (g)	0.0262
Air at 10000m (g)	0.020
Aluminum	205
Argon (g)	0.016
Balsa Wood	0.048
Bitumen	0.7
Bismuth	8.1
Brass	109
Bromine (g)	0.004
Carbon	1.7
Carbon Dioxide (g)	0.0146
Cast Iron	58
Chromium	94
Gasoline	0.15
Iron	80
Nickel	91
Platinum	70
Silver	429
Tungsten	174

Table 1: Thermal Conductivity of Some Common Materials and Elements



Graph 1: Thermal Conductivity of Some Common Materials and Elements

As it is observed from the table and the graph the thermal conductivity of the gasses is the least while that of the solids is more. In solids when a comparison is done it is observed that the metals have a higher conductivity. It is noticed that thermal conductivity is directly proportional to increasing temperature and increasing bulk density. This supports the concept of heat transfer through inter particular interaction.

IV. Dependency of Thermal Conductivity on Temperature

Thermal Conductivity of gas is dependent on absolute temperature. Thermal conductivity is directly proportional to the square root of the absolute temperature. At moderate pressure the spacing between the molecules is largely compacted to the size of a molecule, thus proving that the thermal conductivity is impendent of pressure. The curves in Fig.3 show how the thermal conductivity of some typical gasses and liquids vary with temperature.

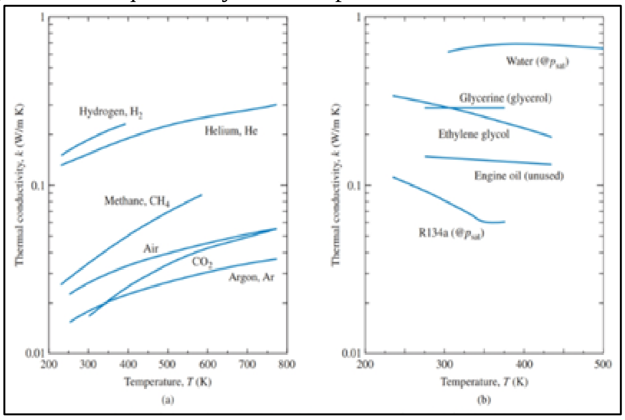


Fig. 3: Relationship bewteen thermal conductivity and temperature of some typical gasses (a) and liquids (b)

Thermal conductivity of a solid material happens due to lattice vibrations and free electron transportation. This is high in those solids with high lattice density such as metals.

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