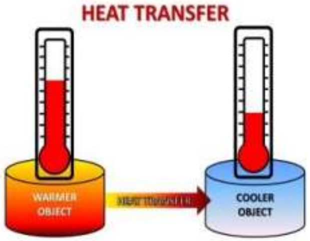
CMET 106

PROCESS HEAT TRANSFER

CHAPTER ONE – PART 1

Introduction and Basic Concepts

Heat Transfer Mechanisms



Objective

- Basic Understanding of heat transfer.
- Know the definition of the three heat transfer modes.
- Know the equation used for each mode.
- Understand the effect of each parameters for each equation.
- Derive the general formula to be applicable for different geometries.
- Calculate the rate of heat transfer

Introduction To Heat Transfer Process

Heat transfer is commonly encountered in **engineering systems** and other aspects of life, and one does not need to go very far to see some application areas of heat transfer. Many ordinary household applications are designed, in whole or part, by using **the principles of heat transfer.**

The engineering activity is directed to ***the controlled release of power*** from **fossil fuels**, and with making that power available where it is needed. **The laws of heat transfer** are of the utmost importance in these activities. The generation of power from the energy changes of chemical reactions involves ***the transfer of vast quantities of thermal energy***. Further, chemical processes of combustion yield temperatures at which most constructional materials would melt; adequate protection by heat transfer equipment is therefore vital. The distribution of energy as electricity is accompanied, at all stages, by certain wastages manifested as rising temperature of the equipment. Heat transfer considerations enable these temperatures to be controlled within safe limits.

The laws of heat transfer find application in many fields of engineering such as ***chemical*** and ***process engineering***, ***manufacturing*** and ***metallurgical industries***.

The forms of energy are numerous such as **heat** , **thermal**, ***mechanical***, ***kinetic***, ***potential***, ***electrical***, ***magnetic***, ***chemical***, and ***nuclear***, and the sum of these energies are known as ***total energy E of a system***

Energy Transfer

Energy can be Transferred to or from a given mass by two mechanisms: **heat transfer Q** and Work W. **An energy interaction** is heat transfer if its driving force is a ***temperature difference***. Otherwise, it is work.

What is Heat Transfer?

heat is known as ***the form of energy*** that can be transferred from one place to another due to a ***temperature difference***.

The science that deals with the determination of the rates such energy transfers is ***the heat transfer***

"The transfer of energy as heat is always from the higher-temperature medium to the lower-temperature one, and heat transfer stops when the two mediums reach the same temperature".

"Heat can be transferred in three different modes: *conduction*, *convection* and *radiation*, and all modes are from the high-temperature medium to a low-temperature one".

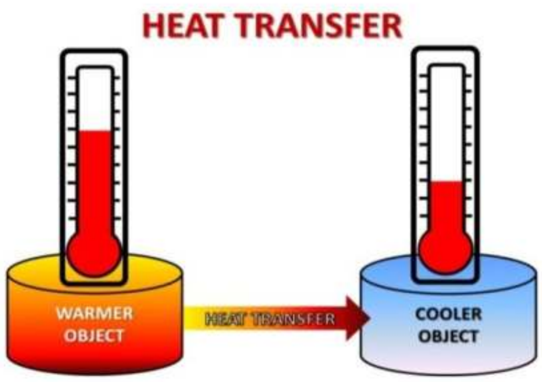


Figure1.1. heat transfers from higher temperature to the lower one

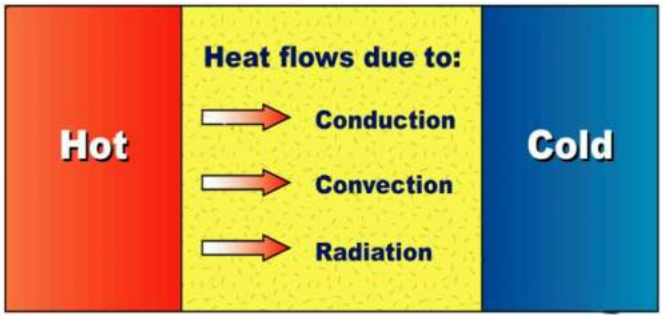


Figure1.2. The three mechanisms of heat transfer

First Mode

Conduction Heat Transfer

Heat Conduction:

Conduction is the transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as a result of **interactions between particles**. Conduction can take place in **solids**, liquids, or gases.

In gases and liquids, conduction is due to the collisions and diffusion of the molecules during their random motion.

In solids, it is due to the combination of vibrations of molecules in a lattice and the energy transport by free electrons.

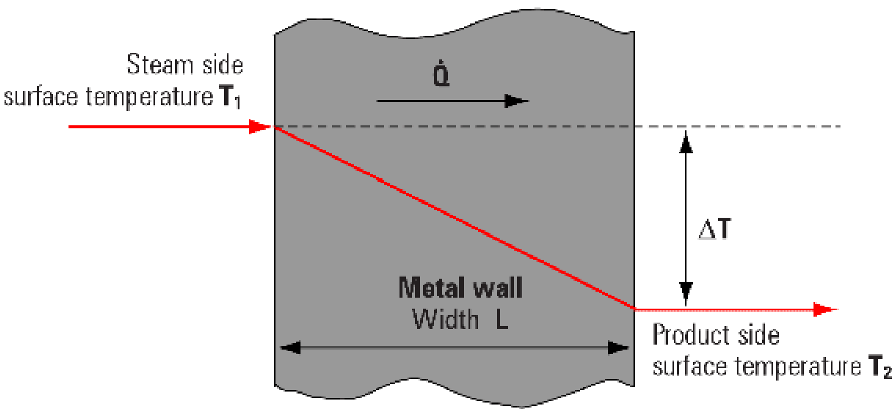


Figure1.3. Heat conduction transfer through a metal

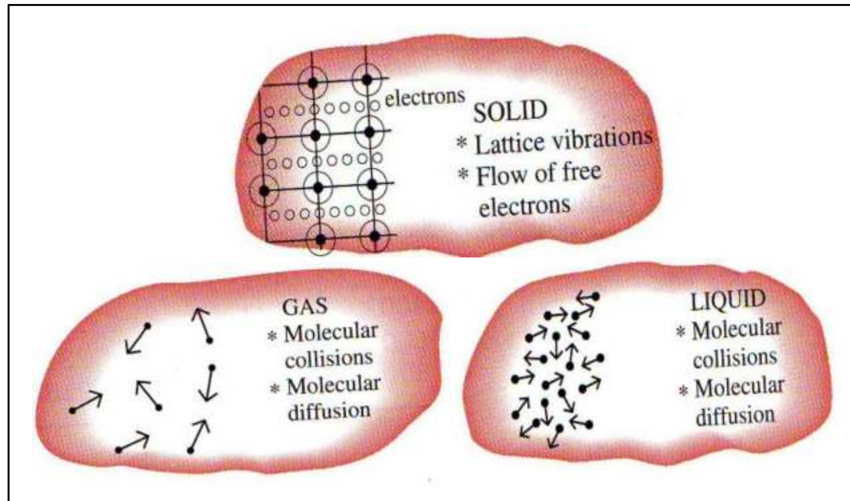


Figure1.4. The mechanism of heat conduction in different phases of a substance

The rate of heat conduction through a medium depends on the ***geometry*** of the medium, Its ***thickness***, and the ***material*** of the medium, as well as the ***temperature difference*** across the medium.

Fourier's Law of Heat Conduction

Experiments have shown that *the rate of heat conduction through a plan layer is proportional to the temperature difference across the layer and the heat transfer area, but inversely proportional to the thickness of the layer. That is*

$$Rate\ of\ heat\ condution \propto \frac{(Area)(Temperature\ difference)}{Thickness}$$

For Heat Conduction,

the rate equation is known as Fourier's law:

$$\dot{Q}_{cond} = -kA\frac{dT}{dx} \qquad (W)$$

$\dot{Q}_{cond}$: *the rate of heat flow (in the x − direction),* $\frac{J}{s}$ *or Watt*

k : *thermal conductivity,* $W/(mK)$

A : *the Area of flow ,* m^2

$\left(-\frac{dt}{dx}\right)$: temperature gradient. K/m

Where the constant of proportionality k is the thermal conductivity of the material.

Thermal Conductivity, k:

is the measure of the ability of a material to conduct heat

Thermal Conductivity *k* *Vs* *Specific Heat Cp*

It is known that there are different materials that can store heat differently. ***The specific heat Cp is defined as a measure of a materials ability to store thermal energy.*** For instance, Cp = 4.18 KJ/Kg.℃ for water and Cp = 0.45 KJ/Kg.℃ for iron at room temperature, which indicates that water can store almost 10 times the energy that iron can per unit mass. Likewise, ***the thermal conductivity k is a measure of a materials ability to conduct heat***. For instance, k = 0.607 W/m.K for water and k = 80.2 W/m.K for iron at room temperature, which indicate that iron conducts heat 100 times faster than water could. Thus, water is considered a poor conductor relative to iron, although water is an excellent medium to store thermal energy. From Fourier's law equation, the thermal conductivity of material can be defined as ***the rate of heat transfer through a unit thickness of material per unit area per unit temperature difference.***

A *high value* for thermal conductivity indicates that the material is **a *good heat conductor***, and ***a low value*** indicate that the material is **a *poor heat conductor or insulator***. (Fig.1.6)

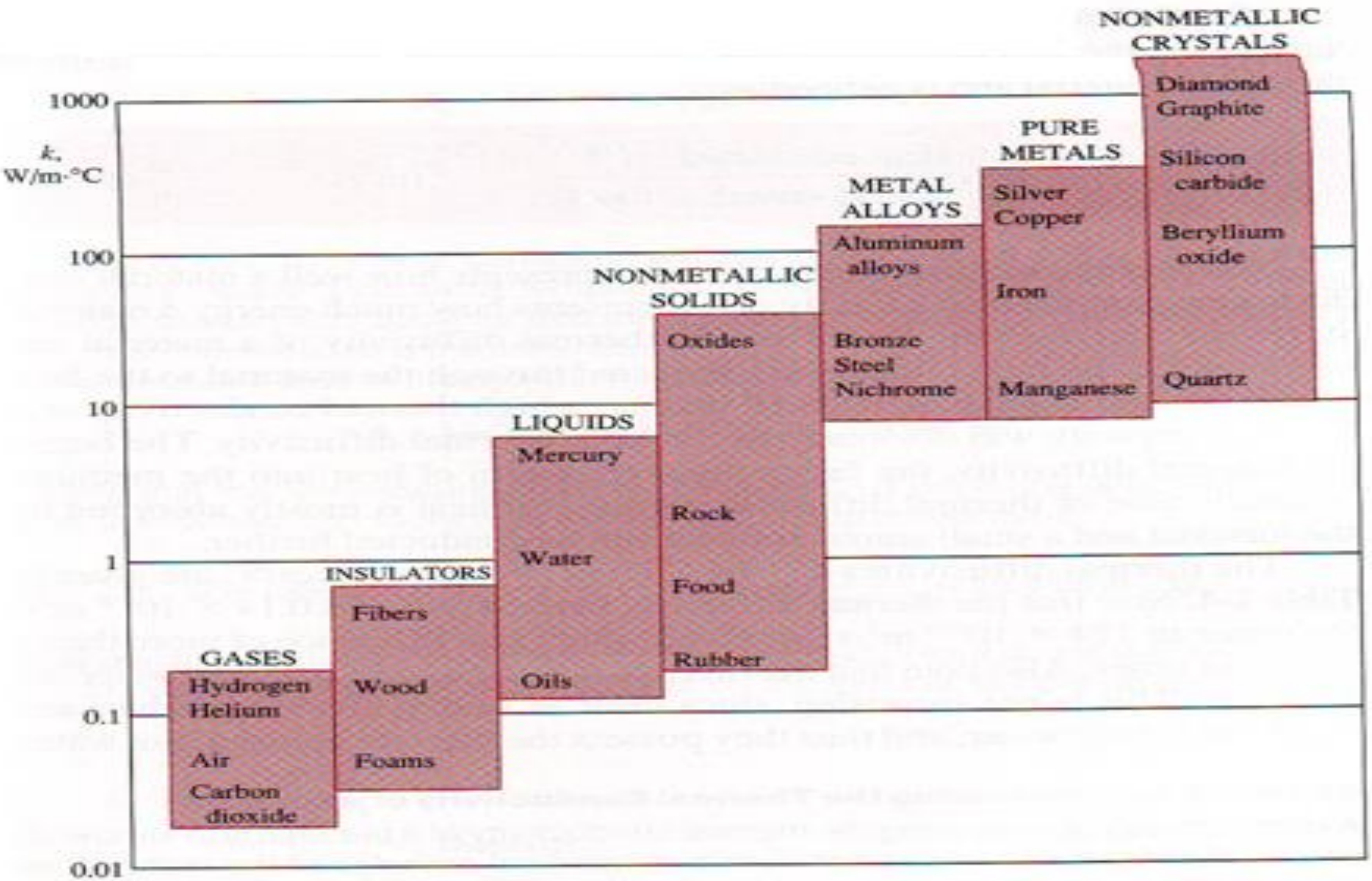


Figure 1.5 Different values of thermal conductivity for different materials.

According to the thermal conductivity value, solid materials may be divided into two groups, **metallic and non-metallic**. Table 1.1 lists conductivity values for some of the more useful materials. The high values of conductivity of metals are attributable to the well ordered crystalline structure of the material. The close arrangement of molecules permits a rapid transfer of energy and, in addition, free electrons play a considerable part. Metals such as copper which are good electrical conductors also conduct heat well.

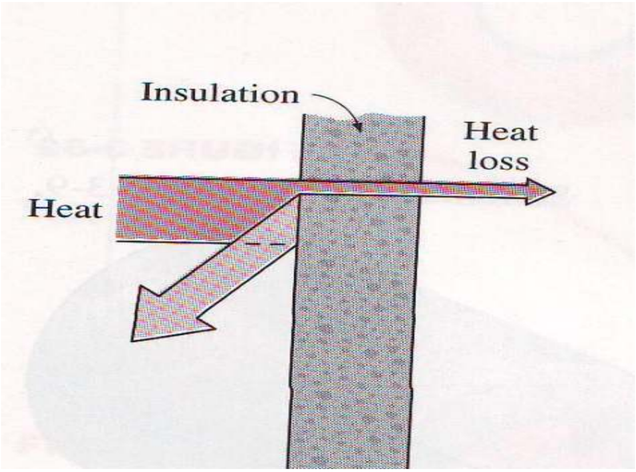
Table 1.1 Thermal Conductivity of Various Materials at 0°C

Materials	Thermal conductivity k W/m . °C	Thermal conductivity k Btu/h . ft. °F
Metals:		
Silver (pure)	410	237
Copper (pure)	385	223
Aluminum (pure)	202	117
Nickel (pure)	93	54
Iron (pure)	73	42
Carbon steel, 1%C	43	25
Lead (pure)	35	20.3
Chrome-nickel steel (18% Cr, 8% Ni)	16.3	9.4
Non-metallic solids:		
Quartz, parallel to axis	41.6	24
Magnesite	4.15	2.4
Marble	2.08-2.94	1.2–1.7
Sandstone	1.83	1.06
Glass, window	0.78	0.45
Maple or oak	0.17	0.096
Sawdust	0.059	0.034
Glass wool	0.038	0.022

In contrast, non-metals do not have a well ordered crystalline structure and, in addition, are often porous in nature. Thus energy transfer between molecules is seriously impeded, and the values of conductivity are much lower. The small pores within the material, being full of air, further restrict the flow of heat since gases are poor conductors.

Thermal Insulation

Thermal insulations are materials or combinations of materials that are used primarily to provide resistance to heat flow .



Most of insulations are heterogeneous materials made of low thermal conductivity materials, and they involve air pockets.

Figure1.6 Thermal insulation retards heat transfer by acting as a barrier in the path of heat flow.

Thermal Resistance (R)

Thermal resistance is a measure of a material's ability to resist heat transfer and its unit is ˚C/W.