People's Democratic Republic Of Algeria
MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH
Abdelhafid Boussouf University Center - Mila
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Process Engineering Department

Introduction to Transport Phenomena

Course Notes

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Chapter 2

Heat Transfer

I. Conduction Heat Transfer

1. INTRODUCITON

Conduction heat transfer is *transfer of thermal energy* from **more energetic** to **less energetic** particles due to their interaction.

<u>Example 01</u>:

A one side steel plate is exposed to Bunsen burner; molecules **get more energy** from that heat and start to **vibrate**. They vibrate, interact with their neighbors **exchanging energy** and this energy goes from the hot side to the cold side, by **conduction**.

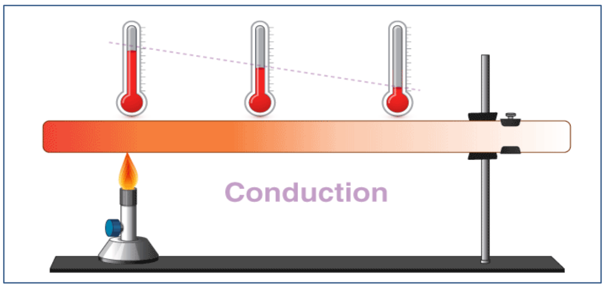


Figure 1 – Conduction heat transfer

Heat transported through a **stationary medium** (solid or fluid without motion) by vibrational energy of molecules that increase with temperature.

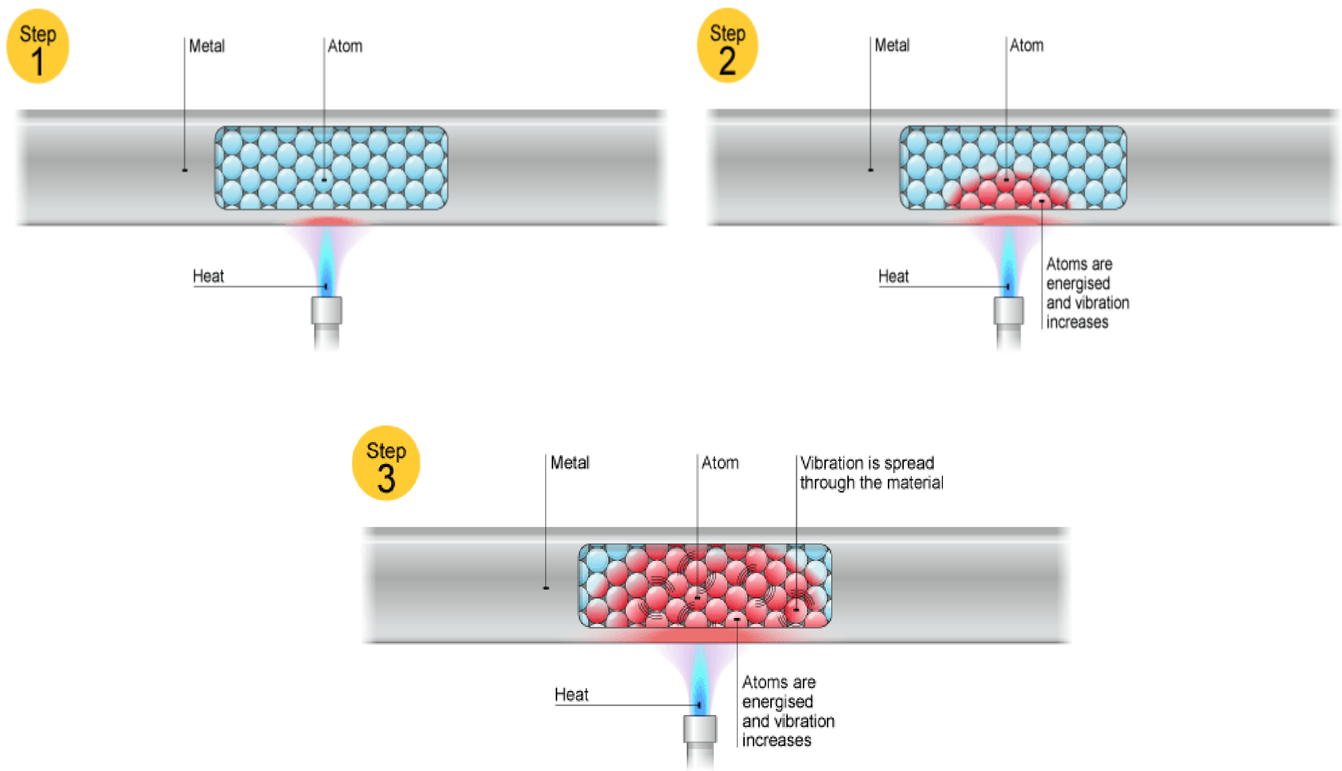


Figure 2 – Transport of heat by particles vibrations.

2. FOURIER'S LAW:

To calculate this conduction, we will write down the *Fourier's Law*.

Conductive heat flux ($q_x^{"}$) is proportional to the temperature gradient ($\frac{dT}{dx}$). The constant of proportionality is a property of the material called: thermal conductivity (k). Thus

$$q_x^{"} = -k.\frac{dT}{dx}$$

x: means that heat transfer in one-dimensional direction ***x***.

<u>Units</u>: $q_x^{"} : \frac{\mathrm{W}}{\mathrm{m}^2}$; $k : \frac{\mathrm{W}}{\mathrm{m.K}}$

Let's take:

$$\frac{dT}{dx} = \frac{T_2 - T_1}{L - 0} = \frac{T_2 - T_1}{L}$$

$$q_x^{"} = -k.\left(\frac{T_2 - T_1}{L}\right) = k.\left(\frac{T_1 - T_2}{L}\right) = k.\left(\frac{\Delta T}{L}\right)$$

$$q_x^{"} = k.\left(\frac{\Delta T}{L}\right)$$

Heat flux is the heat transfer rate (q_x) per unit area (**A**).

So, the heat transfer rate is:

$$q_x = k.\left(\frac{\Delta T}{L}\right)$$

With,

A: area normal to heat transfer.

3. THE CONDUCTION RATE EQUATION:

Fourier's law is phenomenological; that is, it's developed from observed phenomena rather than being derived from first principals.

<u>Example 02</u>:

Consider the cylindrical rod of metal (**Figure 2**), this rod is insulated on its lateral surface, while its ends faces are maintained at different temperatures, with $\mathbf{T_1 > T_2}$.

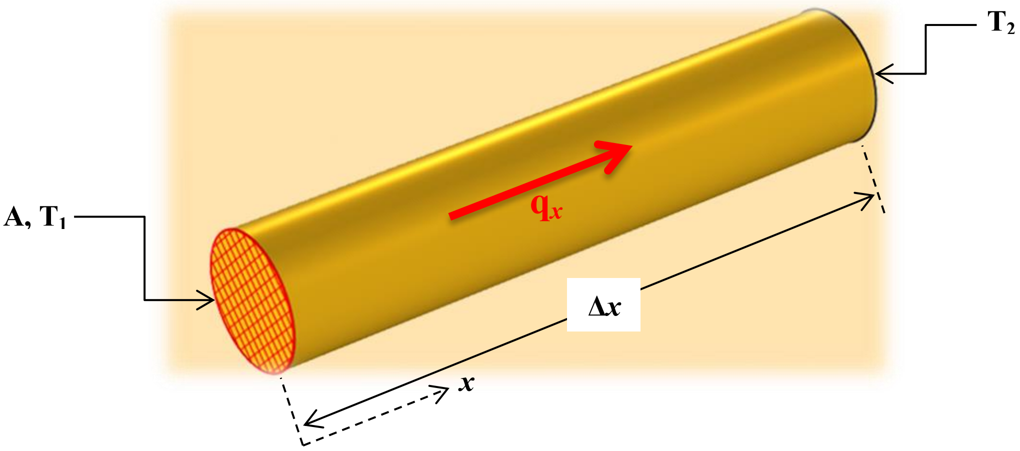


Figure 3 – Transport of heat in cylindrical metal rod.

The temperature difference causes conduction heat transfer in the positive *x*-direction.

We are able to measure the heat transfer rate (q_x) and we seek to determine how (q_x) depends on the following variables: **ΔT**, **Δ*x***, and **A**.

We might imagine:

Holding **ΔT and Δ*x* *constants;***	And varying **A** →	q_x proportional to **A.**
Holding **ΔT and A *constants;***	And varying **Δ*x*** →	q_x varies inversely with **Δ*x*.**
Holding **A and Δ*x* *constants;***	And varying **ΔT** →	q_x proportional to **ΔT.**

The collective effects are then:

$$q_x \propto A.\frac{\Delta T}{\Delta x}$$

With changing the material (e. g. from metal to a plastic), the proportionality remains valid.

For equal values of of: **ΔT**, **Δ*x***, and **A**, the value of q_x would be smaller for the plastic than for the metal.

This suggests that the proportionality may be converted to equality by introducing a coefficient that is a measure of the material behavior.

Hence, we write:

$$q_x = k.A.\left(\frac{\Delta T}{\Delta x}\right)$$

For : $\Delta x \rightarrow 0$, we obtain for the heat rate:

$$q_x = -k.A.\frac{dT}{dx}$$

<u>RECALL THAT</u>: the minus (-) means: heat is always transferred in the direction of decreasing temperature.

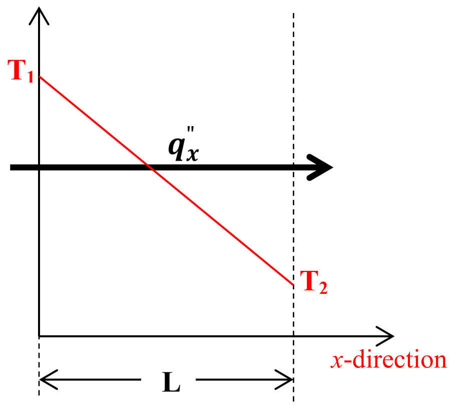
Heat flux is a directional quantity.

Direction of (q''_x) is normal to the cross-sectional area **A** or direction of (q''_x) will always be normal to a surface of constant temperature, called: **an isothermal surface**.

Temperature gradient ($\frac{dT}{dx}$) is **negative.**

From that equation: (q''_x) is **positive**.

Note that the isothermal surface surfaces are planes normal to the *x*-direction.



4. THE THERMAL CONDUCTIVITY:

Based on our life experiences, we know that some materials (like metals) conduct heat at a much faster rate than other materials (like glass). **Thermal conductivity** of a material is a measure of its intrinsic ability to conduct heat.

Metals conduct heat much faster to our hands, which is why we use oven mitts when taking a pie out of the oven.

Plastic is a bad conductor of heat, so we can touch an iron without burning our hands.

Thermal conductivity of a material can be defined as the heat flux transmitted through a material due to a unit temperature gradient under steady-state conditions. It is a material property (independent of the geometry of the object in which conduction is occurring).

$$k_x = -\frac{q''_x}{(\frac{\partial T}{\partial x})}$$

4.1. Thermal Conductivity of Different Materials

Metals are typically good conductors of heat, and hence have high thermal conductivity. Gases generally have low thermal conductivity and are bad conductors of heat (or, in other words, are good insulators).

The table below shows typical values of thermal conductivity for various materials at 0°C:

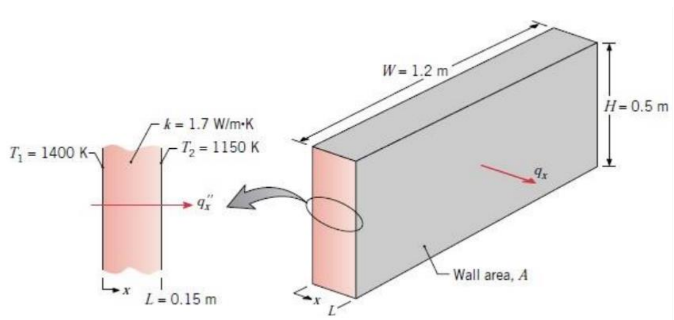
Material	Silver	Copper	Pure iron	Steel	Plastic	Glass	Wood	Water	Air
Thermal conductivity (W $m^{-1}K^{-1}$)	429	403	86.5	51.0	0.17-0.5	0.4 – 1.0	0.16 – 0.25	0.599	0.0226

Good conductors — Good insulators

Reducing thermal conductivity →

Exercise 01

The wall of an industrial furnace is constructed from **0.15-m-thick** fireclay brick having a thermal conductivity of **1.7 W/m^{-1}.K^{-1}**. Measurements made during steady-state operation reveal temperatures of **1400** and **1150 K** at the inner and outer surfaces, respectively. What is the rate of heat loss through a wall that is **0.5 m x1.2 m** on a side?



Exercise 02

The concrete (***k* = 1.4 w/m^{-1}. K^{-1}**) slab of a basement is **11** m long, **8m** wide and **0.2 m** thick. During the winter temperatures are normally **17 ºC** and **10** ºC at the top and the bottom surfaces respectively. What is the rate of heat loss through the slab?