Notions of Transport Phenomena

Dr. Mohamed BOUTI

Abd El-Hafid Boussouf University Center - Mila

Institute of Sciences & Technology

Department of Process Engineering

E-mail: bouti.m@centre-univ-mila.dz

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Objectives

At the end of this course, the student will be able to:

- **Describe** the fundamental principles of *transport phenomena* ;
    - **Identify** the basic modes of *transfer phenomena* ;
- **Illustrate** the initial calculations of *heat transfer*.

Introduction

In engineering, the study of *transport phenomena*, also known as *transfer phenomena*, concerns the ***exchange*** of mass, heat and momentum between observed and studied systems.

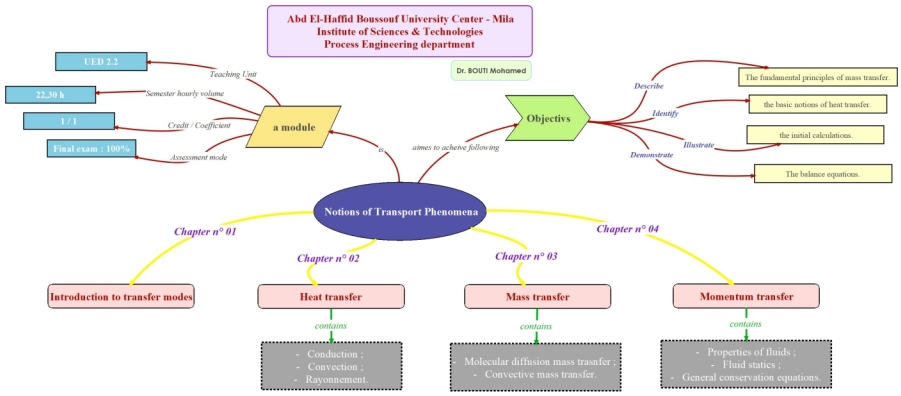


Image 1 Conceptual course map

To approach this subject, students must have acquired sufficient knowledge in ***thermodynamics***, and ***chemical kinetics*** (*as pre-requisites*).

Quiz : Test Pre-requisite

[solution n°1 p. 10]

I

Test n°1: thermodynamiques

State the equation that presents the first law of thermodynamics.

Test n°2: chemical kinetiks

Calculate the overall order of a reaction which has the rate expression (R) below :

$$R = k[A]^{\frac{1}{2}}[B]^{\frac{3}{2}}$$

Chapter 1: Introduction to transfer modes

II

1. Introduction

Transfer phenomena consists of three related subjects: *heat transfer*, *mass transfer*, and *fluid dynamics*. heat transfer deals with the transport of energy, mass transfer is concerned with the transport of mass of various chemical species, and Fluid dynamics involves the transport of momentum.

These three transport phenomena should, at the introductory level, be studied together for the following reasons:

- They frequently occur simultaneously in industrial problems ;
- The basic equations that describe the three transport phenomena are closely related ;
- The mathematical tools needed for describing these phenomena are very similar ;
- The molecular mechanisms underlying the various transport phenomena are very closely related.

2. 1. Transfer phenomena

The most well known transfer phenomena are:

a) Heat transfer: *Definition*

in which the transferred quantity is **heat** (**temperature** or **energy**), this transfer occurs between two zones with *different temperatures*, it always occurs **from the higher temperature to the lower temperature**. The temperature difference is called the *driving force of heat transfer*.

b) Mass transfer: *Definition*

in which the transferred quantity is **matter** (**mass concentration**), this transfer occurs between two zones with *different mass concentrations*. It always occurs **from the higher concentration to the lower concentration**. The concentration difference is called the *driving force of mass transfer.*

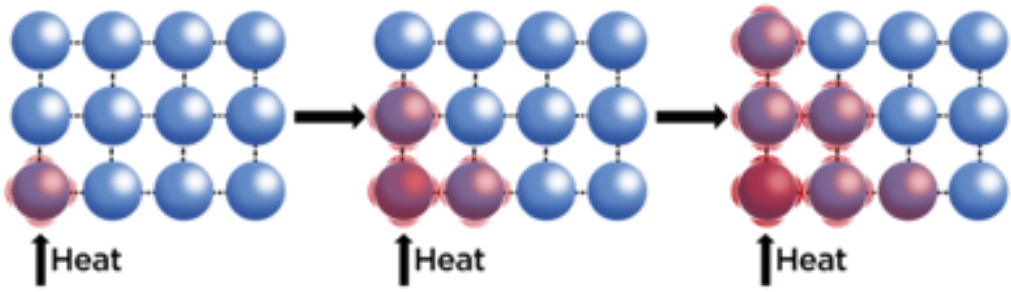
c) Momentum transfer: *Definition*

in this process, the quantity transferred is **momentum** (**velocity**). It occurs between two entities with *different velocities*, always f**rom the entity with the higher velocity to the one with the lower velocity**. The difference in velocity is referred to as the *driving force of momentum transfer*.

3. 2. Transfer modes

3.1. 2.1. Conduction transfer

Conduction is a mode of heat transfer that does not require the movement of matter. Heat is transferred from one atom to another through **simple atomic agitation**. The efficiency of this transfer **increases** with a greater temperature difference (driving force) between two materials. However, it also depends on the *thermal conductivity* of the materials. Heat transfer occurs through direct contact between two stationary solids at different temperatures.



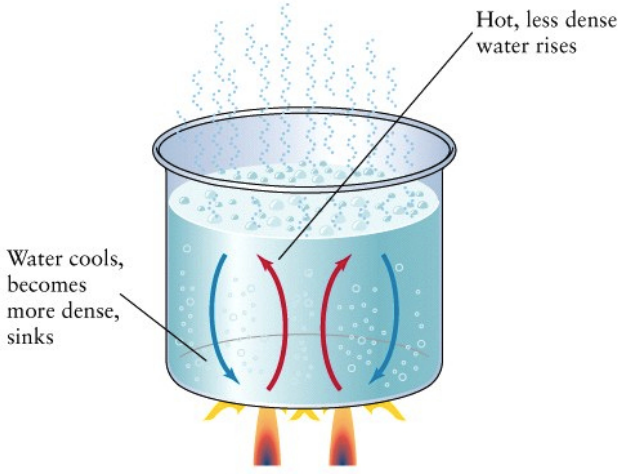
3.2. 2.2. Convective transfer

The exchange of heat **between a surface and a moving fluid in contact with it**, or the transfer of heat within a fluid through the collective movement of its molecules from one point to another. In the process of convection, **heat always moves from hot regions to cold regions**.

- Convection is the transfer of heat with the transfer of mass ;
- Common phenomenon (weather, domestic heating...).

Example

It is through convection that heat, transmitted to water inside a boiler, is transported to the different rooms of an apartment.

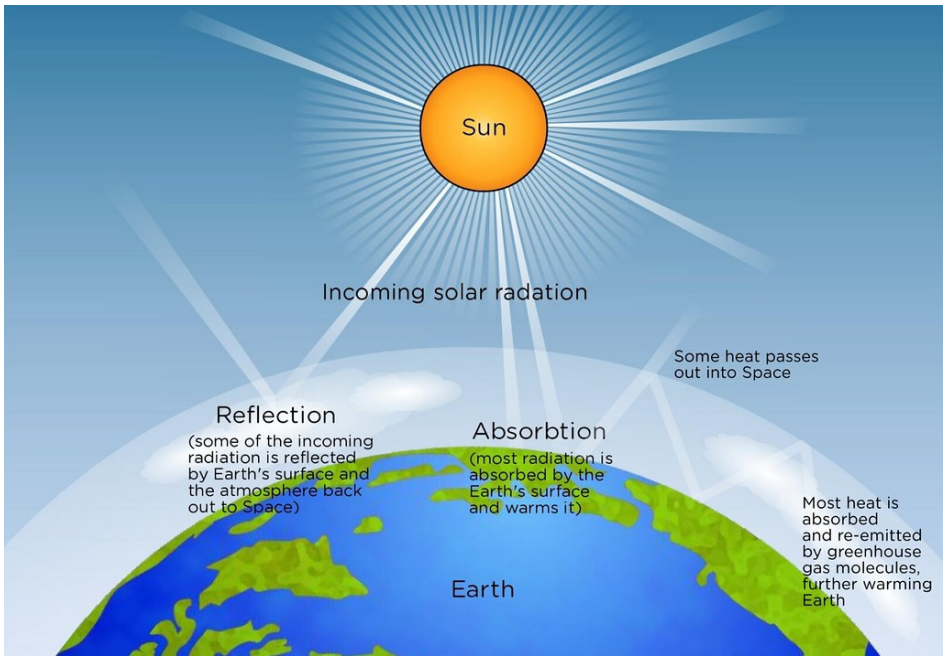


3.3. 2.3. Radiation Transfer

Radiation is an original mode of transfer **specific to** thermal energy. A heated particle *emits* **electromagnetic radiation** in all directions. When this radiation strikes an object, the object can **reflect** a portion of it and **absorb** another portion as heat, which it will use to increase its temperature. This type of heat transfer is analogous to the propagation of light and **does not require any material medium**, unlike the first two modes of transfer. **Gases, liquids, and solids are capable of emitting and absorbing thermal radiation**.

Example

The heat received by the Earth from the Sun is **achieved through radiation**.



4. Quiz : Assessment end chapter

[solution n°2 p. 10]

Quiz

The difference in concentration of matter is :

- ○ The driving force of heat transfer.
- ○ The mass concentration.
- ○ The driving force of mass transfer.

Quiz

Which transferred quantities are referred to for heat, mass, and momentum transfers?

- ☐ Lenght.
- ☐ Temperature.
- ☐ Weight.
- ☐ Concentration.
- ☐ Force.
- ☐ Velocity.

Quiz

When does conduction occurs ?

Quiz

The effeciency of conduction heat transfer deponds on :

- ☐ Velocity of fluid flow.
- ☐ The difference in temperature.
- ☐ The thermal conductivity.
- ☐ Electromagnetic waves.

Quiz

Convection heat transfer is the exchange of heat between :

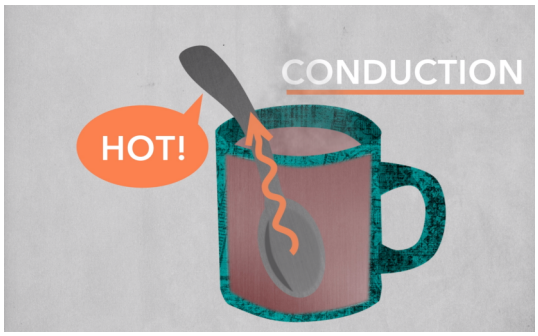
Quiz

Does radiation requires material medium for propagation of electromagnetic waves ?

- ○ Yes, it does.
- ○ Non, it does not.

Conclusion

As conclusion, conduction heat transfer is the transfer of thermal energy[1] between two objects by direct contact.



In-class final exercises n°01

(see In-class exercises n°01.pdf)

1. https://www.sciencedirect.com/topics/engineering/thermal-energy

Exercise solutions

Solution n°1

[exercice p. 4]

Test n°1: thermodynamiques

State the equation that presents the first law of thermodynamics.

During a transformation, we have

Q we have

$$U_2 - U_1 = W + Q$$

With :

$$U_2 - U_1 : variation\ of\ internal\ energy\ , W : received\ work\ , Q : received\ heat$$

Test n°2: chemical kinetiks

Calculate the overall order of a reaction which has the rate expression (R) below :

$$R = k[A]^{\frac{1}{2}}[B]^{\frac{3}{2}}$$

To calculate the overall order of the reaction:

Q Rate is :

$$R = k[A]^{x}[B]^{y}$$

Then,

$$order = x + y$$

So, order = 1/2 + 3/2 = 2, i.e., second order

Solution n°2

[exercice p. 7]

Quiz

The difference in concentration of matter is :

- ○ The driving force of heat transfer.
- ○ The mass concentration.
- ◉ The driving force of mass transfer.

Quiz

Which transferred quantities are referred to for heat, mass, and momentum transfers?

- ☐ Lenght.
- ☑ Temperature.
- ☐ Weight.

- [x] Concentration.
- [ ] Force.
- [x] Velocity.

Quiz

When does conduction occurs ?

Conduction heat transfer occurs through direct contact between two stationary solids at different temperatures.

Quiz

The effeciency of conduction heat transfer deponds on :

- [ ] Velocity of fluid flow.
- [x] The difference in temperature.
- [x] The thermal conductivity.
- [ ] Electromagnetic waves.

Quiz

Convection heat transfer is the exchange of heat between :

Convection heat transfer is the exchange of heat between a surface and a moving fluid in contact with it.

Quiz

Does radiation requires material medium for propagation of electromagnetic waves ?

- ○ Yes, it does.
- ◉ Non, it does not.

Bibliography

[Transport Phenomena] R. Byron Bird, Edwin N. Lightfoot, Warren E. Stewart,Transport Phenomena, Revised 2nd Ed. ISBN: 978-0-470-60692-6