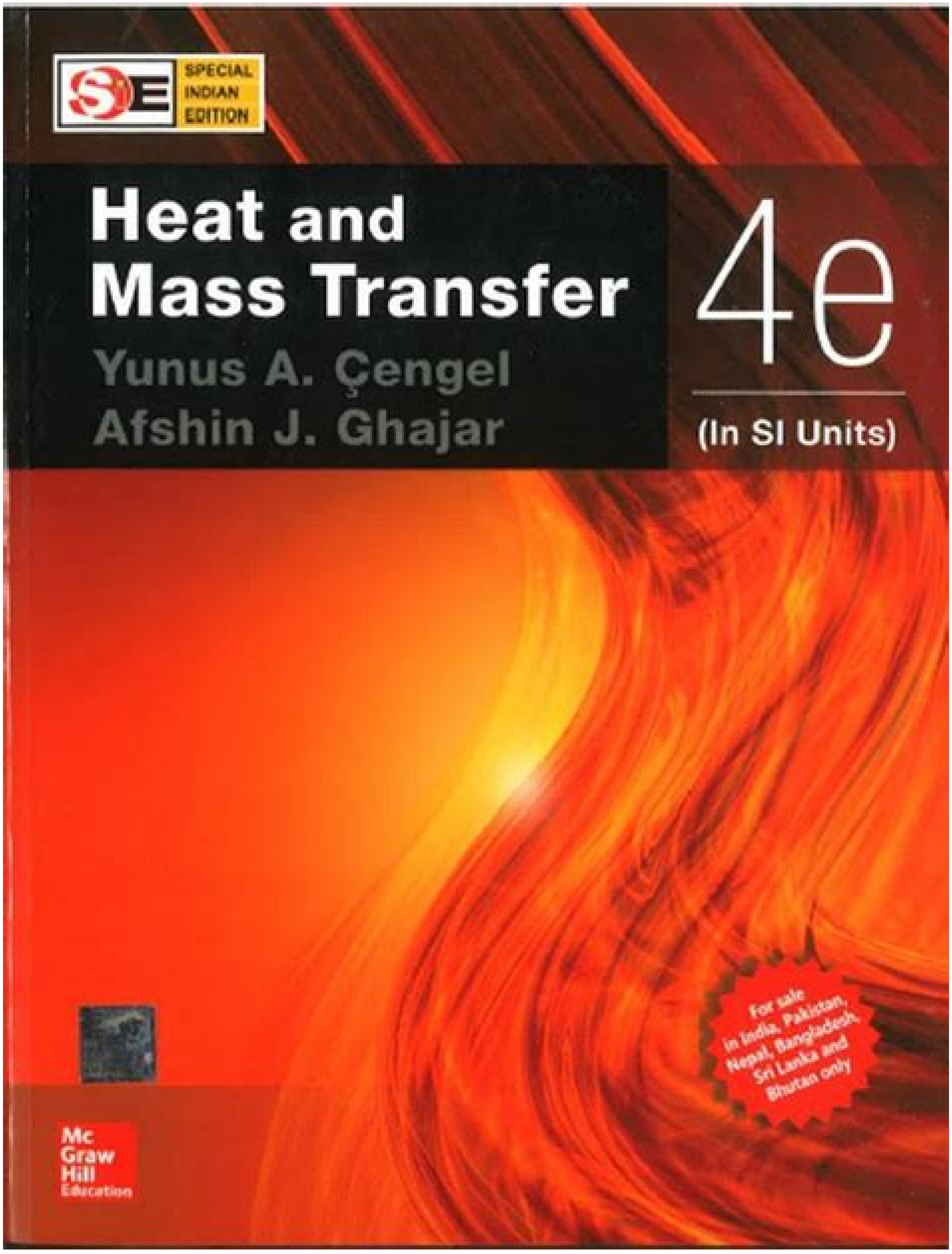
Fundamental Of Heat And Mass Transfer


SPECIAL INDIAN EDITION
Heat and Mass Transfer
Yunus A. Çengel
Afshin J. Ghajar
4e
(In SI Units)
For sale in India, Pakistan, Nepal, Bangladesh, Sri Lanka and Bhutan only
Mc Graw Hill Education

Fundamentals of Heat and Mass Transfer

Heat and mass transfer are essential processes in various fields of engineering and science. Understanding these fundamental principles is crucial for designing systems and processes that involve thermal energy and the movement of mass. This article will delve into the principles of heat transfer, mass transfer, and their interrelationship, providing a comprehensive overview of these topics.

Introduction to Heat Transfer

Heat transfer is the movement of thermal energy from one physical system to another. It occurs due to a temperature difference between the systems or within a system. The three primary modes of heat transfer are conduction, convection, and radiation.

1. Conduction

Conduction is the transfer of heat through a solid material without any motion of the material itself. The heat transfer occurs due to the interaction of molecules and atoms, where higher-energy particles collide with lower-energy ones, transferring energy.

- Fourier's Law of Heat Conduction: This law states that the rate of heat transfer (Q) through a material is proportional to the negative gradient of temperature (dT/dx) and the area (A) through which heat is being conducted. Mathematically, it can be expressed as:

$$ Q = -k \cdot A \cdot \frac{dT}{dx} $$

Where:
- Q = rate of heat transfer (W)
- k = thermal conductivity of the material (W/m·K)
- A = cross-sectional area (m^2)
- $\frac{dT}{dx}$ = temperature gradient (K/m)

- Thermal Conductivity: Different materials have different thermal conductivities, which affect how quickly they can transfer heat. Metals typically have high thermal conductivity, while insulation materials have low thermal conductivity.

2. Convection

Convection is the transfer of heat between a solid surface and a fluid (liquid or gas) in motion. It can be classified into two types: natural convection and forced convection.

- Natural Convection: This occurs due to buoyancy forces that arise from density differences in the fluid caused by temperature variations. For example, warm air rises while cooler air descends.

- Forced Convection: In this case, an external force, such as a fan or pump, induces fluid motion. This enhances heat transfer rates compared to natural convection.

- Newton's Law of Cooling: The rate of heat transfer by convection can be expressed as:

$$ Q = h \cdot A \cdot (T_s - T_\infty) $$

Where:
- Q = heat transfer rate (W)
- h = convective heat transfer coefficient (W/m^2·K)
- A = surface area (m^2)
- T_s = surface temperature (K)
- T_∞ = fluid temperature far from the surface (K)

3. Radiation

Radiation is the transfer of heat in the form of electromagnetic waves, primarily infrared radiation. Unlike conduction and convection, radiation does not require a medium to transfer heat.

- Stefan-Boltzmann Law: The total energy radiated per unit surface area of a black body per unit time is proportional to the fourth power of its absolute temperature:

$$ E = \sigma \cdot T^4 $$

Where:
- E = emissive power (W/m^2)
- σ = Stefan-Boltzmann constant ($5.67 \times 10^{-8} \, \text{W/m}^2\text{K}^4$)
- T = absolute temperature (K)

- Emissivity: Real surfaces emit less thermal radiation compared to a perfect black body. Emissivity is a measure of how effectively a surface emits energy as radiation, ranging from 0 to 1.

Introduction to Mass Transfer

Mass transfer involves the movement of mass from one location to another, driven by concentration gradients, temperature differences, or external forces. It is crucial in various natural and industrial processes, such as diffusion, mixing, and chemical reactions.

1. Diffusion

Diffusion is the process by which molecules move from an area of higher concentration to an area of lower concentration. Fick's laws of diffusion describe this phenomenon.

- Fick's First Law: It states that the flux of a diffusing substance is proportional to the concentration gradient:

$$ J = -D \cdot \frac{dC}{dx} $$

Where:
- J = diffusion flux (mol/m^2·s)
- D = diffusion coefficient (m^2/s)
- $\frac{dC}{dx}$ = concentration gradient (mol/m^3·m)

- Fick's Second Law: This law describes the change in concentration over time:

$$ \frac{\partial C}{\partial t} = D \cdot \frac{\partial^2 C}{\partial x^2} $$

2. Convection in Mass Transfer

Similar to heat transfer, convection also plays a role in mass transfer. This occurs when a fluid carries particles from one location to another, enhancing the mass transfer rate.

- Mass Transfer Coefficient: The rate of mass transfer due to convection can be described by an equation analogous to Newton's law of cooling:

$$ J = k_m \cdot A \cdot (C_s - C_\infty) $$

Where:
- J = mass transfer rate (mol/s)
- k_m = mass transfer coefficient (m/s)
- A = area (m^2)
- C_s = concentration at the surface (mol/m^3)
- C_∞ = bulk concentration (mol/m^3)

Interrelationship Between Heat and Mass Transfer

Heat and mass transfer processes are often interconnected, particularly in systems involving phase changes, such as evaporation and condensation. Here are some key points illustrating their interrelationship:

- Phase Change: During phase changes, such as boiling or condensation, heat transfer is directly related to mass transfer. For example, when water boils, heat is supplied to convert liquid water into vapor, which involves the transfer of mass from the liquid phase to the vapor phase.

- Energy and Mass Balance: In many engineering applications, both energy and mass balances must be considered. For example, in chemical reactors, the reaction rates can be affected by temperature (heat transfer) and concentration (mass transfer).

- Biot Number: The Biot number (Bi) is a dimensionless quantity that relates the rate of heat transfer by conduction within a solid to the rate of heat transfer by convection to a fluid surrounding it. It helps in understanding the relative importance of conduction and convection in heat and mass transfer processes.

$$ Bi = \frac{hL_c}{k} $$

Where:
- h = convective heat transfer coefficient
- L_c = characteristic length
- k = thermal conductivity

Applications of Heat and Mass Transfer

Understanding heat and mass transfer principles is critical in various applications, including:

1. Heat Exchangers: Devices designed to transfer heat between two or more fluids, widely used in HVAC systems, power plants, and refrigeration.

2. Distillation Columns: Used in the separation of mixtures based on differences in boiling points and mass transfer processes.

3. Chemical Reactors: Where reactions occur, and both heat and mass transfer are crucial for optimizing yield and efficiency.

4. Food Processing: Involves heat transfer for cooking and mass transfer for preserving food, such as dehydration and fermentation.

5. Environmental Engineering: In waste treatment processes, where mass transfer is essential for pollutant removal, and heat transfer is vital in thermal treatments.

Conclusion

The fundamentals of heat and mass transfer are essential for understanding various physical and engineering processes. By comprehending the mechanisms of conduction, convection, and radiation in heat transfer, as well as diffusion and convection in mass transfer, engineers and scientists can design and optimize systems across a range of applications. As technology advances, the importance of these principles continues to grow, making their study vital for innovation and efficiency in numerous industries.

Frequently Asked Questions

What is the difference between heat transfer and mass transfer?

Heat transfer refers to the movement of thermal energy from one object or substance to another due to a temperature difference, while mass transfer involves the movement of mass from one location to another, which may occur due to concentration gradients or other driving forces.

What are the three modes of heat transfer?

The three modes of heat transfer are conduction, convection, and radiation. Conduction occurs through direct contact, convection involves the movement of fluids, and radiation is the transfer of heat through electromagnetic waves.

What is Fourier's Law of Heat Conduction?

Fourier's Law states that the rate of heat transfer through a material is proportional to the negative gradient of temperature and the area through which the heat is being transferred, expressed mathematically as $q = -kA(dT/dx)$, where q is the heat transfer rate, k is the thermal conductivity, A is the area, and dT/dx is the temperature gradient.

How does convection differ from conduction?

Convection involves the transfer of heat by the physical movement of a fluid (liquid or gas), while conduction is the transfer of heat through a solid material without any movement of the material itself.

What is the significance of the Nusselt number in heat transfer?

The Nusselt number is a dimensionless number that characterizes the convective heat transfer relative to conductive heat transfer. It helps in determining the efficiency of heat exchange in fluid flow and is used in designing heat exchangers.

What is the role of thermal conductivity in heat transfer?

Thermal conductivity is a material property that indicates how well a material can conduct heat. Higher thermal conductivity means that a material can transfer heat more efficiently, which is crucial in applications like insulation and heat exchangers.

What is the principle of mass transfer in diffusion?

The principle of mass transfer in diffusion states that particles move from an area of higher concentration to an area of lower concentration, driven by concentration gradients, until equilibrium is reached.

What factors affect convective heat transfer?

Factors affecting convective heat transfer include fluid velocity, temperature difference between the fluid and the surface, fluid properties (like viscosity and density), and surface roughness.

What is the importance of the Reynolds number in mass transfer?

The Reynolds number is a dimensionless quantity that helps predict flow patterns in different fluid flow situations. It is crucial in mass transfer as it indicates whether the flow is laminar or turbulent, affecting the efficiency of mass transfer processes.

How does temperature affect the rate of heat transfer?

The rate of heat transfer generally increases with an increase in temperature difference between two objects or fluids, as greater differences enhance the driving force for heat transfer, whether by conduction, convection, or radiation.

Find other PDF article:
https://soc.up.edu.ph/47-print/files?trackid=PdZ79-3503&title=pmbok-5th-edition-torrent.pdf

Fundamental Of Heat And Mass Transfer

essential、basic、fundamental、fundamental分别是什么意 **...**
Dec 24, 2023 · essential、basic、fundamental、fundamental分别是什么意思？这四个词语的区别在于它们强调的重点不同。"Essential"强调必须的、不可或缺的，是指某件事情不可缺少的一部分；"Basic"强调基

essential ,basic,fundamental,vital的区别？_百度知道
essential ,basic,fundamental,vital的区别？一、词义辨析不一样1 、essential adj. 必要的，重要的，基本的〔辨析〕语气较强，强调极其重要、必不可少的，暗含某物如缺少某部分，则失去其本质特征的意味。〔例证〕Wa

英文**fundamental**是什么意思_百度知道
Dec 17, 2024 · 在学术和日常交流中，“fundamental”一词频繁出现，其意义深远。在英语中，它作为形容词，意指事物的基础性、重要性和不可忽视的本质属性。例如，当我们谈论教育时，基础教育被视为“fundamental”，因为它为后续学习打下坚实的基础。 “Fundamental”同样可以作为名词使用，指的是基本原则或 ...

高中英语，请问*be fundamental to*和*be fundamental for* 有什么区 …

Apr 11, 2020 · be fundamental to 英 美 对 … 是必要的（不可缺的）be fundamental to的用法和样例：例句Agreements are fundamental to business practices. 协议是商业活动的基本形式。be fundamental for 是什么的基本 The traning includes the core competencies that are fundamental for law enforcement and successful criminal prosecution.

请问谐波分析中，纵坐标代表什么意思？希望大家帮忙。_百度知道

Mar 1, 2013 · 请问谐波分析中，纵坐标代表什么意思？希望大家帮忙。Mag表示幅值。Fundamental是基础的意思，在这里表示基波幅值。上图中，纵坐标表示的是谐波的幅值与基波幅值的比例的百分数。

be fundamental to是什么意思 **-** 百度知道

Apr 21, 2015 · be fundamental to是什么意思be fundamental to 英 美 对 … 是必要的（不可缺的）be fundamental to的用法和样例：例句Agreements are fundamental to business practices.协议是商业活动的基本形式。

hotmail邮箱怎么登录？_百度知道

Feb 21, 2024 · 登录后缀@hotmail.com的邮箱一共有三种方法，具体如下：方法一：官方登陆入口 首先我们想到的一定是官网登陆，是的，这也是最快捷的登陆方式。hotmail邮箱官网登陆地址： www.hotmail.com 大家复制到浏览器打开，点击登陆按钮，输入我们的hotmail邮箱账号密码即可成功登陆，不过这种方式是网页版使用 …

elementary , fundamental , primary和underlying 之间的区别详 …

Apr 6, 2011 · elementary 基本的，初级的，元素的。The question is（elementary）。这个问题很简单。fundamental 基本的，根本的，重要的，侧重指作为基础、根本的抽象的事物。There is a（fundamental）difference in attitude between these two politicians. 这两位政治家的态度有着根本的区别。primary 首要的，主要，初级的，初等 …

foundational和**fundamental**区别 **-** 百度知道

Nov 10, 2014 · foundational和fundamental区别fundamental 意思是基本的，foundational 是基础（意思是地基的意思）。。。意思不一样。比如，this is our fundamental rights（这是我们基本的权利）vs this is a foundational cla

用*powergui*的*FFT*分析时总是提示*simulation time of the signal is …*

仿真完成后，采用Powergui分析FFT，有时会发生错误："simulation time of the signals is not enough long for the given fundamental frequency". 很多论坛说是仿真时间短了，可能这也是原因，不过更有可能是这样：FFT的数据来自于示波器SCOPE，在SCOPE PARAMETERS/GENERAL选项卡/SAMPLING 中,有DECIMATION和SAMPLE TIME两 …

*essential、basic、fundamental、fundamental*分别是什么意 …

Dec 24, 2023 · essential、basic、fundamental、fundamental分别是什么意思？这四个词语的区别在于它们强调的重点不同。"Essential"强调必须的、不可或缺的，是指某件事情不可缺少的 …

*essential ,basic,fundamental,vital*的区别？_百度知道

essential ,basic,fundamental,vital的区别？一、词义辨析不一样1、essential adj. 必要的，重要的，基本的〔辨析〕语气较强，强调极其重要、必不可少的，暗含某物如缺少某部分，则失去其 …

英文*fundamental*是什么意思_百度知道

Dec 17, 2024 · 在学术和日常交流中，"fundamental"一词频繁出现，其意义深远。在英语中，它作为形容词，意指事物的基础性、重要性和不可忽视的本质属性。例如，当我们谈论教育时，基 …

高中英语，请问*be fundamental to*和*be fundamental for* 有什么区 …

Apr 11, 2020 · be fundamental to 英 美 对 … 是必要的（不可缺的）be fundamental to的用法和样例：例句Agreements are fundamental to business practices. 协议是商业活动的基本形式。be …

请问谐波分析中，纵坐标代表什么意思？希望大家帮忙。_百度知道

Mar 1, 2013 · 请问谐波分析中，纵坐标代表什么意思？希望大家帮忙。Mag表示幅值。Fundamental是基础的意思，在这里表示基波幅值。上图中，纵坐标表示的是

谐波的幅值与基 …

be fundamental to是什么意思 - 百度知道

Apr 21, 2015 · be fundamental to是什么意思be fundamental to 英 美 对 … 是必要的 (不可缺的)be fundamental to的用法和样例: 例句Agreements are fundamental to business practices.协议是 …

hotmail邮箱怎么登录? _百度知道

Feb 21, 2024 · 登录后缀@hotmail.com的邮箱一共有三种方法，具体如下：方法一：官方登陆入口 首先我们想到的一定是官网登陆，是的，这也是最快捷的登陆方式。hotmail邮箱官网登陆地 …

elementary , fundamental , primary和underlying 之间的区别详 …

Apr 6, 2011 · elementary 基本的，初级的，元素的。The question is （elementary）。这个问题很简单。fundamental 基本的，根本的，重要的，侧重指作为基础、根本的抽象的事物。 …

foundational和fundamental区别 - 百度知道

Nov 10, 2014 · foundational和fundamental区别fundamental 意思是基本的，foundational 是基础（意思是地基的意思）。。。意思不一样。比如，this is our fundamental rights （这是我们基 …

用powergui的FFT分析时总是提示simulation time of the signal is …

仿真完成后，采用Powergui分析FFT，有时会发生错误："simulation time of the signals is not enough long for the given fundamental frequency". 很多论坛说是仿真时间短了，可能这也是原 …

Explore the fundamental of heat and mass transfer in our comprehensive guide. Understand key principles and applications. Learn more and enhance your knowledge today!

Back to Home