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第2版

改编版

HEAT TRANSFER

A PRACTICAL APPROACH (Second Edition)

YUNUS A. ÇENGEL 著

冯妍卉 贾 力 张欣欣 彭晓峰 改编

高等教育出版社
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内容提要

本书是由 Yunus A.Çengel 编著的《Heat Transfer: a Practical Approach》(Second edition)改编而成。

本书主要内容有:一维及多维非稳态导热、稳态导热,导热问题的数值求解;层流、湍流状态的强制对流换热,自然对流换热;沸腾和凝结换热;辐射传热,气体辐射,换热器分析计算等。

本书可作为高等学校能源动力类、机械类、土建类等专业开展传热学双语教学的教材,也可供其他院校相关专业选用,亦可供工程技术人员参考。

序　言

我国古代传说：燧人氏钻木取火以化腥臊，被奉为千古圣皇；古希腊神话：普罗米修斯盗天火开罪于主神而泽惠天下，被崇为世间英雄。在古代各民族的语言里，“火”与“热”几乎是同义语。关于热的学问起源于人类对于热与冷现象本质的追求，这种追求可能是人类最初对自然界法则的追求之一。

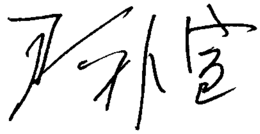
20 世纪最伟大的物理学家 A. 爱因斯坦在他与 L. 英费尔德合著的《物理学的进化》一书中明确指出：“用来描述热现象的最基本的概念是温度和热，在科学史上经过了非常长的时间才把这两个概念区别开来，但是一经辨别清楚，就使得科学得到了飞速的发展”。现在人们已经认同，热能是人类赖以生存的能量形式之一，热量传递是自然界与科学技术领域中最普遍存在的物理现象之一。

从宇宙的起源到纳米器件的制造，从传统的冶金工业到现代的生物技术，几乎所有自然科学和工程技术领域都离不开热能利用和热量传递的强化与减弱。无论在一个物体内部或是一些物体之间，只要存在温度差，热量就会以某一种方式或同时以某几种方式，自发地从高温处传向低温处。传热学就是研究自然界与科学技术领域中最普遍存在的热量传递现象的基本规律及其应用的一门科学。

英语是当今世界使用最广泛的语言之一，在促进世界各地区、各民族信息交流方面起着越来越明显的作用，特别是随着互联网技术的飞速普及，英语几乎成为人们交流的最重要的媒介。今天，无论是科学技术人员，或是行政管理人员，或是服务行业的从业人员，都已经认识到熟练掌握英语的必要性。我国高等学校陆续开设各种学科门类的“双语教学”课程正是顺应这种趋势的体现。所谓“双语教学”，是指非外语课程利用母语和外语两种语言授课的一种教学方法。通过双语教学，希望能使学生获得专业知识、强化外语能力，并逐步养成用外语思考的习惯。根据美国南加州大学 Krashen 教授所提出的著名的“输入假说”，教师在中文讲述的基础上，适当采用英语教学，让学习难度略高于学生的接受和理解能力，给学生一个“跳摘”

的机会，能增强学生的学习动力。

本教材是根据我国的国情需要和编者的教学经验，由美国内华达州立大学（里诺）Dr. Yunus A. Çengel 所著《Heat Transfer：a Practical Approach》（Second edition）（由 New York，WCB/McGraw-Hill Inc. 出版）改编而成，供传热学双语教学使用。



2007 年初春

Preface

In the ancient history, people drilled wood to make fire in order to remove fishy smell of raw meat or fish. At that time, in any language, the word 'heat' is synonymous with 'fire'. People's continuously seeking the nature of hot and cold phenomena contributes to the formation of thermal science.

In the book "The Evolution of Physics", A. Einstein, the greatest physical scientist in the 20th century pointed out definitely as "The most fundamental concepts in the description of heat phenomena are temperature and heat. It took an unbelievably long time in the history of science for this to be distinguished, but once this distinction was made rapid progress resulted". Nowadays, people have knowledge that heat is one kind of energy human's life depends on and heat transfer is one of the most common physical phenomena in the nature, science and technology.

From the origin of cosmic to the fabrication of nano-equipment, from traditional metallurgy to modern biology technology, almost all natural sciences and engineering fields involve the utilization of thermal energy, the promotion or weakening of heat transfer. The energy transfer is always from the higher temperature medium to the lower temperature one if only the presence of a temperature difference. The science that deals with the determination of the rates of such energy transfers is heat transfer.

English has been one of the most important communication media with the world globalization and widespread of the Internet. Furthermore, China has entered the WTO, she hungers for persons having strong professional knowledge as well as high English level. Bilingual teaching has become an urgent task for China education, especially for high education. As one of teaching reformation, Bilingual teaching is to use both native language and English in non-English Class. It's our goal that from bilingual teaching on heat transfer course, the students not only get knowledge and technology in the field of heat transfer, but also improve their special English with enlarged vocabulary and thinking with English. We believe the famous "Input Hypothesis" of Prof. Krashen, if the requirement for study is a little higher than the receptivity of students, it will be an impetus for their study.

This text book, used for bilingual teaching in China, is according to nationwide needs and the editors' teaching experience, and adapted from the book "Heat Transfer: a Practical Approach (2nd edition)" wrote by Dr. Yunus A. Çengel in the university of Nevada, Reno, and published by WCB/McGraw-Hill Inc.

In the Spring of 2007

改编者的话

本书是在 Yunus A. Çengel 编著《Heat Transfer：a Practical Approach》（Second Edition）的基础上，根据我国高校热能与动力工程专业双语教学的实际情况改编而成的。

本书的原版教材强调传热过程的物理机理和工程实践，突出必要简洁的理论推演，尽可能略去烦琐的数学，旨在通过简单而又不失准确的方法向未来的工程师直接传递传热学知识，激发他们的学习兴趣、创造性和对客观事物的深入了解。传热学原理建立于实验观察基础之上，本书所有内容的引出都是基于物理角度，便于读者理解和接受，其趣味性、可读性较强，图示、例题较多，侧重对问题、方法和结论的归纳、理解、比较，能适应自学的要求，以期让学生能享受传热学知识学习的乐趣，并提升求知欲。基于以上的特色，改编者又全面考虑我国高校传热学课程教学和双语教学的实际情况对原版教材进行了改编。

在改编过程中，为保证原版教材的风格，对原版教材的内容只进行了删减，未改变书中不同于我国习惯用法的一些物理量的规范和用法以及一些标准。为便于教与学，在教材后面增加了中英文词汇对照。为适应多媒体教学的需求，改编者还研制了与本书配套的多媒体课件和电子习题解答。

本书主要内容有：一维及多维非稳态导热、稳态导热，导热问题的数值求解；层流、湍流状态的强制对流换热，自然对流换热；沸腾和凝结换热；辐射传热，气体辐射，换热器分析计算等。本书可作为高等学校能源动力类、机械类、土建类等专业开展传热学双语教学的教材，也可供其他院校相关专业选用，亦可供工程技术人员参考。

由于改编者的水平有限，难免存在不当和缺欠之处，诚恳祈望广大读者不吝赐教。

改编者

2006－12

PREFACE

OBJECTIVES

Heat transfer is a basic science that deals with the rate of transfer of thermal energy. This introductory text is intended for use in a first course in heat transfer for undergraduate engineering students, and as a reference book for practicing engineers. The objectives of this text are

- To cover the *basic principles* of heat transfer.
- To present a wealth of real-world *engineering applications* to give students a feel for engineering practice.
- To develop an *intuitive understanding* of the subject matter by emphasizing the physics and physical arguments.

Students are assumed to have completed their basic physics and calculus sequence. The completion of first courses in thermodynamics, fluid mechanics, and differential equations prior to taking heat transfer is desirable. The relevant concepts from these topics are introduced and reviewed as needed.

In engineering practice, an understanding of the mechanisms of heat transfer is becoming increasingly important since heat transfer plays a crucial role in the design of vehicles, power plants, refrigerators, electronic devices, buildings, and bridges, among other things. Even a chef needs to have an intuitive understanding of the heat transfer mechanism in order to cook the food "right" by adjusting the rate of heat transfer. We may not be aware of it, but we already use the principles of heat transfer when seeking thermal comfort. We insulate our bodies by putting on heavy coats in winter, and we minimize heat gain by radiation by staying in shady places in summer. We speed up the cooling of hot food by blowing on it and keep warm in cold weather by cuddling up and thus minimizing the exposed surface area. That is, we already use heat transfer whether we realize it or not.

GENERAL APPROACH

This text is the outcome of an attempt to have a textbook for a practically oriented heat transfer course for engineering students. The text covers the standard topics of heat transfer with an emphasis on physics and real-world applications, while de-emphasizing intimidating heavy mathematical aspects. This approach is more in line with students' intuition and makes learning the subject matter much easier.

The goal throughout this project has been to offer an engineering textbook that

- Talks directly to the minds of tomorrow's engineers in a *simple yet precise* manner.
- Encourages *creative thinking* and development of a *deeper understanding* of the subject matter.
- Is *read* by students with *interest* and *enthusiasm* rather than being used as just an aid to solve problems.

Special effort has been made to appeal to readers' natural curiosity and to help students explore the various facets of the exciting subject area of heat transfer.

Yesterday's engineers spent a major portion of their time substituting values into the formulas and obtaining numerical results. However, now formula manipulations and number crunching are being left to computers. Tomorrow's engineer will have to have a clear understanding and a firm grasp of the *basic principles* so that he or she can understand even the most complex problems, formulate them, and interpret the results. A conscious effort is made to emphasize these basic principles while also providing students with a look at how modern tools are used in engineering practice.

Yunus A.Çengel

NOMENCLATURE

A_s	Surface area, m^2
A_c	Cross-sectional area, m^2
Bi	Biot number
C	Specific heat, kJ/kg · K
C_c, C_h	Heat capacity rate, W/℃
C_D	Drag coefficient
C_f	Friction coefficient
C_p	Constant pressure specific heat, kJ/kg · K
C_v	Constant volume specific heat, kJ/kg · K
d, D	Diameter, m
D_h	Hydraulic diameter, m
erfc	Complementary error function
E	Total energy, kJ
E_b	Blackbody emissive flux
$E_{b\lambda}$	Spectral blackbody emissive flux
f	Friction factor
f_λ	Blackbody radiation function
F	Force, N
F_D	Drag force, N
F_{ij}, $F_{i \to j}$	View factor
g	Gravitational acceleration, m/s^2
G	Incident radiation, W/m^2
Gr	Grashof number

h	Convection heat transfer coefficient, W/m^2 · ℃
h_c	Thermal contact conductance, W/m^2 · ℃
h_{fg}	Latent heat of vaporization, kJ/kg
j_H	Colburn j-factor
J	Radiosity, W/m^2; Bessel function
k	Thermal conductivity, W/m · ℃
k_{eff}	Effective thermal conductivity, W/m · ℃
L	Length; half thickness of a plane wall
L_c	Characteristic or corrected length
L_h	Hydrodynamic entry length
L_t	Thermal entry length
m	Mass, kg
$\dot{m}$	Mass flow rate, kg/s
NTU	Number of transfer units
Nu	Nusselt number
p	Perimeter, m
P	Pressure, kPa
P_v	Vapor pressure, kPa
Pr	Prandtl number
$\dot{q}$	Heat flux, W/m^2
Q	Total heat transfer, kJ
$\dot{Q}$	Heat transfer rate, kW
r_{cr}	Critical radius of insulation
R	Gas constant, kJ/kg · K
R	Radius, m
R	Thermal resistance, ℃/W
R_c	Thermal contact resistance, m^2 · ℃/W

R_f	Fouling factor
Ra	Rayleigh number
Re	Reynolds number
S	Conduction shape factor
Sc	Schmidt number
Sh	Sherwood number
St	Stanton number
t	Time, s
t	Thickness, m
T	Temperature, ℃ or K
T_b	Bulk fluid temperature, ℃
T_f	Film temperature, ℃
T_{sat}	Saturation temperature, ℃
T_s	Surface temperature, ℃ or K
u, v	x- and y-components of velocity
U	Overall heat transfer coefficient, $W/m^2 \cdot ℃$
V	Total volume, m^3
$\dot{V}$	Volume flow rate, m^3/s
$\mathcal{V}$	Velocity, m/s
$\mathcal{V}_m$	Mean velocity, m/s
$\mathcal{V}_\infty$	Free-stream velocity, m/s
$\dot{W}$	Power, kW

Greek Letters

α	Absorptivity
α	Thermal diffusivity, m^2/s
β	Volume expansivity, 1/K

δ_v	Velocity boundary layer thickness, m
δ_t	Thermal boundary layer thickness, m
ΔP	Pressure drop, Pa
ΔT_{lm}	Log mean temperature difference
ε	Emissivity; heat exchanger or fin effectiveness
η_{fin}	Fin efficiency
η_{th}	Thermal efficiency
μ	Dynamic viscosity, kg/m · s or N · s/m^2
ν	Kinematic viscosity = μ/ρ,m^2/s
ν	Frequency, 1/s
ρ	Density, kg/m^3
ρ_s	Relative density
σ	Stefan-Boltzmann constant
σ_n	Normal stress, N/m^2
σ_s	Surface tension, N/m
τ	Shear stress, N/m^2
τ	Transmissivity; Fourier number
τ_s	Wall shear stress, N/m^2
θ	Dimensionless temperature

Subscripts

atm	Atmospheric
b	Boundary; bulk fluid
cond	Conduction
conv	Convection
cyl	Cylinder
e	Exit conditions

f	Saturated liquid; film
i	Inlet, initial, or indoor conditions
i	*i*th component
l	Liquid
m	Mixture
o	Outlet or outdoor conditions
rad	Radiation
s	Surface
surr	Surrounding surfaces
sat	Saturated
semi-inf	Semi-infinite medium
sph	Sphere
sys	System
v	Water vapor
1	Initial or inlet state
2	Final or exit state
∞	Far from a surface; free-flow conditions

Superscripts

(over dot) Quantity per unit time