时代教育·国外高校优秀教材精选

Mc Graw Hill Education

工程热力学

THERMODYNAMICS AN ENGINEERING APPROACH

（英文影印版·原书第7版）

[美] 尤努斯 A.切盖尔（YUNUS A. ÇENGEL）
迈克尔 A.博尔斯（MICHAEL A. BOLES） 著

机械工业出版社
CHINA MACHINE PRESS

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本书介绍了工程热力学的基本原理。内容包括：概述与基本概念，能量、能量传递与通用能量分析方法，纯物质的性质，闭口系统的能量分析，控制体积的质量和能量分析，热力学第二定律，熵，㶲，气体动力循环，蒸汽动力循环与联合动力循环，制冷循环，热力学性质关系式，混合气体，气体-蒸汽混合物与空气调节，化学反应，化学与相平衡，以及可压缩流动。

书中提供了大量结合工程应用的实例，可增加读者对工程热力学的兴趣，提高解决实际问题的能力。章后的小结和大量的习题可使读者更好地学习和掌握本书内容。

本书可作为高等院校能源与动力工程、建筑环境与设备工程等相关专业的本科生、研究生教材，也可供有关工程技术人员参考使用。

本书配有学生资源（EES）（光盘号：978-7-89405-933-8），购买本书的读者可发送 Email 至 jx@cmp-hiedu.com 免费索取。

Yunus A. Çengel, Michael A. Boles
Thermodynamics: An Engineering Approach
ISBN: 9780077366742

北京市版权局著作权合同登记 图字：01-2014-3680 号。

图书在版编目（CIP）数据

工程热力学 = Thermodynamics：An Engineering Approach：第 7 版：英文/（美）切盖尔，（美）博尔斯著 . —影印本 . —北京：机械工业出版社，2016. 1

时代教育 · 国外高校优秀教材精选

ISBN 978-7-111-52639-1

Ⅰ. ①工… Ⅱ. ①切…②博… Ⅲ. ①工程热力学—高等学校—教材—英文 Ⅳ. ①TK123

中国版本图书馆 CIP 数据核字（2015）第 310529 号

机械工业出版社（北京市百万庄大街 22 号 邮政编码 100037）

策划编辑：蔡开颖 责任编辑：蔡开颖 宋学敏 版式设计：霍永明

责任校对：张 薇 封面设计：张 静 责任印制：乔 宇

保定市中画美凯印刷有限公司印刷

2016 年 2 月第 1 版第 1 次印刷

203mm × 253mm · 61.5 印张 · 1684 千字

标准书号：ISBN 978-7-111-52639-1

定价：149.00 元

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序

热力学是一门关于能量的学科，既是工程领域的重要组成部分，又与我们的生活密切相关。其应用领域非常广泛，从能源动力到家居设备，从微生物到天体，从物理化学到社会科学，是人们认识世界的重要基石。

美国内华达大学机械工程系尤努斯 A. 切盖尔（Yunus A. Çengel）和北卡罗来纳大学机械和航天工程系的迈克尔 A. 博尔斯（Michael A. Boles）所编著的《工程热力学》（Thermodynamics：An Engineering Approach），从 1989 年第 1 版问世以来，先后于 1994 年、1998 年、2002 年、2006 年、2009 年、2011 年进行了修订，已经是第 7 版了。

我作为清华大学动力工程及工程热物理学科“工程热力学”课程的负责人，从 2002 年开始，大量购买了该书的第 4 版影印本，正式作为课程的辅助教材，每学期上课时，都借给学生使用一学期，所以对于该书比较熟悉。在教学过程中，我总把第 4 版中阿诺德·索末菲（Arnold Sommerfeld）对热力学的有趣描述“Thermodynamics is a funny subject...”作为第一节课绪论的结束语，也经常用该书中的典型问题作为教学实例，取得了很好的效果，同学们课后踊跃阅读。该书已经成为课程教学有益的组成部分。

该书面向大学二年级（或三年级）学生的学习需要，强调对基本的热力学原理的理解和运用。总结起来，有以下几个特点：

1）为了能让中低程度的学生饶有兴趣地进行阅读和学习，书中提供了大量日常生活和工程中有关热力学的典型实例，图文并茂，直观生动，强调物理现象和物理论证，培养学生对热力学的直观理解。每章的开始都有一个本章内容概述和本章的学习目标，每章的最后都有总结，快速回顾基本概念和重要关系式以及指出内容之间的关联，所以特别适合自学。

2）该书特别强调知识的应用，不是要求进行复杂的公式推导和公式的套用，而是讲述将基本原理应用到不同系统的方法，从而搭建起从学习知识到合理运用知识的桥梁，充分体现出了作者所崇尚的“实践是最好的学习方法”的思想。

3）教材的叙述逻辑合理，从概念、物质性质到原理，从熟悉的生活例子到复杂的工程系统，从简单推广到一般，使学生能循序渐进地“畅游”其间。客观和直观的方式贯穿全书，基于日常经验和实验观察并有效利用联想，让读者理解工程科学原理。大多数章节还包含一个叫作“特殊兴趣主题”的部分，会延伸讨论热力学里有关生物、日常生活或社会经济等有趣的主题，如果跳过去也不会影响内容的连续性。

4）该书附有大量的例题和习题，例题都系统地给出了解答步骤，给出答案后紧接着进行了充分的讨论。在章节末引入丰富的实际问题和拓展的设计题，以及针对热力学课程特点的与经济和环境有关的题目，使学生在掌握解决问题的能力的同时，增强节能、环保、安全和经济可行性的意识。

5）该书有免费的学生资源，其中包含限量版学生版本 Engineering Equation Solver（EES）软件，EES 功能比较强大，以方程或者性质表格的方式内置热力学物性和输运物性，还允许使用者自己输入物性数据或者物性函数关系方程，从而使学生有更多的时间认真思考建模和解决工程问题，软件可以进行优化、参数分析以及线性和非线性回归，还包含书中选出的问题的解答。

第 7 版内容最主要的变化是把大量的图片升级为逼真的三维图并且编入了 400 个新问题。以前版本中最受欢迎的特点全部保留，所有章节的主体部分和附录部分全部的图表都保持原样。现在每一章节至少

包含一个新的例题。第1章中对“量纲与单位”部分做了更新；第6章中对“冰箱、空调和热泵性能”部分增加了新的一段；第8章中对关于热力学第二定律效率的材料进行了更新，热力学第二定律效率定义进行了修改以保持一致性，并且，对“日常生活中的热力学第二定律”部分的讨论做了扩展；第11章增加了一个新的部分叫作“蒸气压缩制冷循环的热力学第二定律分析”。

原书第7版出版的同时还建立了在线网络平台，为教师和学生提供了丰富的资源。通过这个平台，教师可以很方便地在线布置作业、测验和考试，学生也可以根据自己的节奏和时间安排进行练习。这个平台帮助学生建立与课程老师的联系，使得教师的指导不仅是在课程学习期间，而且包括课程结束之后。

综上所述，该书达到了当前国际上“工程热力学”教科书的较高水准，这也是它获得了世界上不少学校的教授和学生的好评的原因。该书可以作为原版教材和教学参考书使用。

史琳教授
清华大学热能工程系
于北京

PREFACE

BACKGROUND

Thermodynamics is an exciting and fascinating subject that deals with energy, which is essential for sustenance of life, and thermodynamics has long been an essential part of engineering curricula all over the world. It has a broad application area ranging from microscopic organisms to common household appliances, transportation vehicles, power generation systems, and even philosophy. This introductory book contains sufficient material for two sequential courses in thermodynamics. Students are assumed to have an adequate background in calculus and physics.

OBJECTIVES

This book is intended for use as a textbook by undergraduate engineering students in their sophomore or junior year, and as a reference book for practicing engineers. The objectives of this text are

- To cover the *basic principles* of thermodynamics.
- To present a wealth of real-world *engineering examples* to give students a feel for how thermodynamics is applied in engineering practice.
- To develop an *intuitive understanding* of thermodynamics by emphasizing the physics and physical arguments.

It is our hope that this book, through its careful explanations of concepts and its use of numerous practical examples and figures, helps students develop the necessary skills to bridge the gap between knowledge and the confidence to properly apply knowledge.

PHILOSOPHY AND GOAL

The philosophy that contributed to the overwhelming popularity of the prior editions of this book has remained unchanged in this edition. Namely, our goal has been to offer an engineering textbook that

- Communicates directly to the minds of tomorrow's engineers in a *simple yet precise* manner.
- Leads students toward a clear understanding and firm grasp of the *basic principles* of thermodynamics.
- Encourages *creative thinking* and development of a *deeper understanding* and *intuitive feel* for thermodynamics.
- Is *read* by students with *interest* and *enthusiasm* rather than being used as an aid to solve problems.

Special effort has been made to appeal to students' natural curiosity and to help them explore the various facets of the exciting subject area of thermodynamics. The enthusiastic responses we have received from users of prior editions—from small colleges to large universities all over the world—and the continued

translations into new languages indicate that our objectives have largely been achieved. It is our philosophy that the best way to learn is by practice. Therefore, special effort is made throughout the book to reinforce material that was presented earlier.

Yesterday's engineer spent a major portion of his or her time substituting values into the formulas and obtaining numerical results. However, formula manipulations and number crunching are now being left mainly to computers. Tomorrow's engineer will need 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 perspective of how computational tools are used in engineering practice.

The traditional *classical*, or *macroscopic*, approach is used throughout the text, with microscopic arguments serving in a supporting role as appropriate. This approach is more in line with students' intuition and makes learning the subject matter much easier.

NEW IN THIS EDITION

The primary change in this seventh edition of the text is the upgrade of a large number of line artwork to realistic three-dimensional figures and the incorporation of about 400 new problems. All the popular features of the previous editions are retained, and the main body of all chapters and all the tables and charts in the Appendix remain mostly unchanged. Each chapter now contains at least one new solved example problem, and a significant part of existing problems are modified. In Chapter 1, the section on Dimensions and Units is updated, and a new subsection is added to Chapter 6 on the Performance of Refrigerators, Air-Conditioners, and Heat Pumps. In Chapter 8, the material on the second-law efficiency is updated, and some second-law efficiency definitions are revised for consistency. Also, the discussions in the section Second-Law Aspects of Daily Life have been extended. Chapter 11 now has a new section titled Second-Law Analysis of Vapor-Compression Refrigeration Cycle.

OVER 400 NEW PROBLEMS

This edition includes over 400 new problems with a variety of applications. Problems whose solutions require parametric investigations, and thus the use of a computer, are identified by a computer-EES icon, as before. Some existing problems from previous editions have been removed from the text.

LEARNING TOOLS

EARLY INTRODUCTION OF THE FIRST LAW OF THERMODYNAMICS

The first law of thermodynamics is introduced early in Chapter 2, "Energy, Energy Transfer, and General Energy Analysis." This introductory chapter sets the framework of establishing a general understanding of various forms of energy, mechanisms of energy transfer, the concept of energy balance, thermo-economics, energy conversion, and conversion efficiency using familiar settings that involve mostly electrical and mechanical forms of energy. It also exposes students to some exciting real-world applications of thermodynamics early in the course, and helps them establish a sense of

the monetary value of energy. There is special emphasis on the utilization of renewable energy such as wind power and hydroulic energy, and the efficient use of existing resources.

EMPHASIS ON PHYSICS

A distinctive feature of this book is its emphasis on the physical aspects of the subject matter in addition to mathematical representations and manipulations. The authors believe that the emphasis in undergraduate education should remain on *developing a sense of underlying physical mechanisms* and a *mastery of solving practical problems* that an engineer is likely to face in the real world. Developing an intuitive understanding should also make the course a more motivating and worthwhile experience for students.

EFFECTIVE USE OF ASSOCIATION

An observant mind should have no difficulty understanding engineering sciences. After all, the principles of engineering sciences are based on our *everyday experiences* and *experimental observations.* Therefore, a physical, intuitive approach is used throughout this text. Frequently, *parallels are drawn* between the subject matter and students' everyday experiences so that they can relate the subject matter to what they already know. The process of cooking, for example, serves as an excellent vehicle to demonstrate the basic principles of thermodynamics.

SELF-INSTRUCTING

The material in the text is introduced at a level that an average student can follow comfortably. It speaks *to* students, not *over* students. In fact, it is *self-instructive.* The order of coverage is from *simple* to *general.* That is, it starts with the simplest case and adds complexities gradually. In this way, the basic principles are repeatedly applied to different systems, and students master how to apply the principles instead of how to simplify a general formula. Noting that the principles of sciences are based on experimental observations, all the derivations in this text are based on physical arguments, and thus they are easy to follow and understand.

EXTENSIVE USE OF ARTWORK

Figures are important learning tools that help students "get the picture," and the text makes very effective use of graphics. This edition of *Thermodynamics: An Engineering Approach,* Seventh Edition contains more figures and illustrations than any other book in this category. Further, a large number of figures have been upgraded to become three-dimensional and thus more real-life. Figures attract attention and stimulate curiosity and interest. Most of the figures in this text are intended to serve as a means of emphasizing some key concepts that would otherwise go unnoticed; some serve as page summaries. The popular cartoon feature "Blondie" is used to make some important points in a humorous way and also to break the ice and ease the nerves. Who says studying thermodynamics can't be fun?

LEARNING OBJECTIVES AND SUMMARIES

Each chapter begins with an *overview* of the material to be covered and chapter-specific *learning objectives.* A *summary* is included at the end of each chapter, providing a quick review of basic concepts and important relations, and pointing out the relevance of the material.

NUMEROUS WORKED-OUT EXAMPLES WITH A SYSTEMATIC SOLUTIONS PROCEDURE

Each chapter contains several worked-out *examples* that clarify the material and illustrate the use of the basic principles. An *intuitive* and *systematic* approach is used in the solution of the example problems, while maintaining an informal conversational style. The problem is first stated, and the objectives are identified. The assumptions are then stated, together with their justifications. The properties needed to solve the problem are listed separately if appropriate. Numerical values are used together with their units to emphasize that numbers without units are meaningless, and that unit manipulations are as important as manipulating the numerical values with a calculator. The significance of the findings is discussed following the solutions. This approach is also used consistently in the solutions presented in the instructor's solutions manual.

A WEALTH OF REAL-WORLD END-OF-CHAPTER PROBLEMS

The end-of-chapter problems are grouped under specific topics to make problem selection easier for both instructors and students. Within each group of problems are *Concept Questions,* indicated by "C," to check the students' level of understanding of basic concepts. The problems under *Review Problems* are more comprehensive in nature and are not directly tied to any specific section of a chapter—in some cases they require review of material learned in previous chapters. Problems designated as *Design and Essay* are intended to encourage students to make engineering judgments, to conduct independent exploration of topics of interest, and to communicate their findings in a professional manner. Problems with the  are solved using EES, and complete solutions together with parametric studies are included on the enclosed DVD. Problems with the  are comprehensive in nature and are intended to be solved with a computer, preferably using the EES software that accompanies this text. Several economics- and safety-related problems are incorporated throughout to enhance cost and safety awareness among engineering students. Answers to selected problems are listed immediately following the problem for convenience to students. In addition, to prepare students for the Fundamentals of Engineering Exam (that is becoming more important for the outcome-based ABET 2000 criteria) and to facilitate multiple-choice tests, over 200 *multiple-choice problems* are included in the end-of-chapter problem sets. They are placed under the title *Fundamentals of Engineering (FE) Exam Problems* for easy recognition. These problems are intended to check the understanding of fundamentals and to help readers avoid common pitfalls.

RELAXED SIGN CONVENTION

The use of a formal sign convention for heat and work is abandoned as it often becomes counterproductive. A physically meaningful and engaging approach is adopted for interactions instead of a mechanical approach. Subscripts "in" and "out," rather than the plus and minus signs, are used to indicate the directions of interactions.

PHYSICALLY MEANINGFUL FORMULAS

The physically meaningful forms of the balance equations rather than formulas are used to foster deeper understanding and to avoid a cookbook approach.

The mass, energy, entropy, and exergy balances for *any system* undergoing *any process* are expressed as

Mass balance:
$$m_{in} - m_{out} = \Delta m_{system}$$

Energy balance:
$$\underbrace{E_{in} - E_{out}}_{\text{Net energy transfer by heat, work, and mass}} = \underbrace{\Delta E_{system}}_{\text{Change in internal, kinetic, potential, etc., energies}}$$

Entropy balance:
$$\underbrace{S_{in} - S_{out}}_{\text{Net entropy transfer by heat and mass}} + \underbrace{S_{gen}}_{\text{Entropy generation}} = \underbrace{\Delta S_{system}}_{\text{Change in entropy}}$$

Exergy balance:
$$\underbrace{X_{in} - X_{out}}_{\text{Net exergy transfer by heat, work, and mass}} - \underbrace{X_{destroyed}}_{\text{Exergy destruction}} = \underbrace{\Delta X_{system}}_{\text{Change in exergy}}$$

These relations reinforce the fundamental principles that during an actual process mass and energy are conserved, entropy is generated, and exergy is destroyed. Students are encouraged to use these forms of balances in early chapters after they specify the system, and to simplify them for the particular problem. A more relaxed approach is used in later chapters as students gain mastery.

TOPICS OF SPECIAL INTEREST

Most chapters contain a section called "Topic of Special Interest" where interesting aspects of thermodynamics are discussed. Examples include *Thermodynamic Aspects of Biological Systems* in Chapter 4, *Household Refrigerators* in Chapter 6, *Second-Law Aspects of Daily Life* in Chapter 8, and *Saving Fuel and Money by Driving Sensibly* in Chapter 9. The topics selected for these sections provide intriguing extensions to thermodynamics, but they can be ignored if desired without a loss in continuity.

GLOSSARY OF THERMODYNAMIC TERMS

Throughout the chapters, when an important key term or concept is introduced and defined, it appears in **boldface** type. Fundamental thermodynamic terms and concepts also appear in a glossary located on our accompanying website (www.mhhe.com/cengel). This unique glossary helps to reinforce key terminology and is an excellent learning and review tool for students as they move forward in their study of thermodynamics. In addition, students can test their knowledge of these fundamental terms by using the flash cards and other interactive resources.

CONVERSION FACTORS

Frequently used conversion factors and physical constants are listed on the inner cover pages of the text for easy reference.

SUPPLEMENTS

The following supplements are related to users of this SI edition.

STUDENT RESOURCE DVD

Engineering Equation Solver (EES)

Packaged free with every new text, the Student Resource DVD contains the Limited Academic Version of EES (Engineering Equation Solver) software with scripted solutions to selected text problems.

Developed by Sanford Klein and William Beckman from the University of Wisconsin—Madison, this software combines equation-solving capability and engineering property data. EES can do optimization, parametric analysis, and linear and nonlinear regression, and provides publication-quality plotting capabilities. Thermodynamics and transport properties for air, water, and many other fluids are built in, and EES allows the user to enter property data or functional relationships.

EES is a powerful equation solver with built-in functions and property tables for thermodynamic and transport properties as well as automatic unit checking capability. It requires less time than a calculator for data entry and allows more time for thinking critically about modeling and solving engineering problems. Look for the EES icons in the homework problems sections of the text.

PROPERTIES TABLE BOOKLET

(ISBN 0-07-735999-2)

This booklet provides students with an easy reference to the most important property tables and charts, many of which are found at the back of the textbook in both the SI and English units.

The following supplements are related to users of the U.S. edition.

McGRAW-HILL CONNECT ENGINEERING

McGraw-Hill Connect Engineering is a web-based assignment and assessment platform that gives students the means to better connect with their coursework, with their instructors, and with the important concepts that they will need to know for success now and in the future. With Connect Engineering, instructors can deliver assignments, quizzes, and tests easily online. Students can practice important skills at their own pace and on their own schedule.

Connect Engineering for *Thermodynamics: An Engineering Approach,* Seventh Edition is available via the text website at www.mhhe.com/cengel.

COSMOS

McGraw-Hill's COSMOS (Complete Online Solutions Manual Organization System) allows instructors to streamline the creation of assignments, quizzes, and tests by using problems and solutions from the textbook, as well as their own custom material. COSMOS is now available online at http://cosmos.mhhe.com/. Note that this resource is based on the U.S. seventh edition and, in recognition of the fact that English units are still used in some industries in the United States, both SI and English units are included.

HANDS-ON MECHANICS

Hands-on Mechanics is a website designed for instructors who are interested in incorporating three-dimensional, hands-on teaching aids into their lectures. Developed through a partnership between the McGraw-Hill Engineering Team and the Department of Civil and Mechanical Engineering at the United States Military Academy at West Point, this website not only provides detailed instructions for how to build 3-D teaching tools using materials found in any lab or local hardware store, but also provides a community where educators can share ideas, trade best practices, and submit their own original demonstrations for posting on the site. Visit www.handsonmechanics.com for more information.

WWW.MHHE.COM/CENGEL

This site offers resources for students and instructors.

The following resources are available for students:

- **Glossary of Key Terms in Thermodynamics**—Bolded terms in the text are defined in this accessible glossary. Organized at the chapter level or available as one large file.
- **Student Study Guide**—This resource outlines the fundamental concepts of the text and is a helpful guide that allows students to focus on the most important concepts. The guide can also serve as a lecture outline for instructors.
- **Learning Objectives**—The chapter learning objectives are outlined here. Organized by chapter and tied to ABET objectives.
- **Self-Quizzing**—Students can test their knowledge using multiple-choice quizzing. These self-tests provide immediate feedback and are an excellent learning tool.
- **Flashcards**—Interactive flashcards test student understanding of the text terms and their definitions. The program also allows students to flag terms that require further understanding.
- **Crossword Puzzles**—An interactive, timed puzzle that provides hints as well as a notes section.
- **Concentration**—An interactive matching game that enhances understanding of basic thermodynamic concepts.
- **Errata**—If errors should be found in the text, they will be reported here.

The following resources are available for instructors under password protection:

- **Instructor Testbank**—Additional problems prepared for instructors to assign to students. Solutions are given, and use of EES is recommended to verify accuracy.
- **Correlation Guide**—New users of this text will appreciate this resource. The guide provides a smooth transition for instructors not currently using the Çengel/Boles text.
- **Image Library**—The electronic version of the figures are supplied for easy integration into course presentations, exams, and assignments.

- **Instructor's Guide**—Provides instructors with helpful tools such as sample syllabi and exams, an ABET conversion guide, a thermodynamics glossary, and chapter objectives.
- **Errata**—If errors should be found in the solutions manual, they will be reported here.
- **Solutions Manual**—The detailed solutions to all text homework problems are provided in PDF form.
- **EES Solutions Manual**—The entire solutions manual is also available in EES. Any problem in the text can be modified and the solution of the modified problem can readily be obtained by copying and pasting the given EES solution on a blank EES screen and hitting the solve button.
- **PP slides**—Powerpoint presentation slides for all chapters in the text are available for use in lectures.
- **Appendix**—This is provided in PDF form for ease of use.

ACKNOWLEDGMENTS

The authors would like to acknowledge with appreciation the numerous and valuable comments, suggestions, constructive criticisms, and praise from the following evaluators and reviewers:

Edward Anderson
Texas Tech University

John Biddle
Cal Poly Pomona University

Gianfranco DiGiuseppe
Kettering University

Shoeleh Di Julio
California State University-Northridge

Afshin Ghajar
Oklahoma State University

Harry Hardee
New Mexico State University

Kevin Lyons
North Carolina State University

Kevin Macfarlan
John Brown University

Saeed Manafzadeh
University of Illinois-Chicago

Alex Moutsoglou
South Dakota State University

Rishi Raj
The City College of New York

Maria Sanchez
California State University-Fresno

Kalyan Srinivasan
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Their suggestions have greatly helped to improve the quality of this text. In particular we would like to express our gratitude to Mehmet Kanoglu of the University of Gaziantep, Turkey, for his valuable contributions, his critical review of the manuscript, and for his special attention to accuracy and detail.

We also would like to thank our students, who provided plenty of feedback from students' perspectives. Finally, we would like to express our appreciation to our wives, Zehra Çengel and Sylvia Boles, and to our children for their continued patience, understanding, and support throughout the preparation of this text.

Yunus A. Çengel
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