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Thermodynamics

An Engineering Approach Fourth Edition

热力学

原理及工程技术应用 第4版

Yunus A. Çengel Michael A. Boles



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FOURTH
EDITION

THERMODYNAMICS

AN ENGINEERING APPROACH

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Thermodynamics An Engineering Approach

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Thermodynamics An Engineering Approach

(Fourth Edition)

影 印 版 序

热力学是一门研究能量的基础学科。长期以来，它一直是世界工程领域中的重要组成部分。此教科书面向工科大学本科，包含足够的内容供两学期连续的热力学课程之用。

全书是用传统的、古典的，即宏观的观点论述，但在适当的场合，采用了补充性的微观解释。这样比较符合学生们的直觉，使学习课程的主要内容变得容易得多。

此教材以简单而又准确的方式直接和明天的科研工作者和工程师们进行交谈，鼓励他们在深入理解基本概念的基础上，进行创造性思维。它是一本学生们能饶有兴趣地、充满热情地阅读的工程教科书，而不是一本只用来帮助解题的参考书。它将带领充满好奇心的学子们在热力学这一神奇的世界里进行一次愉快的旅行，使他们能探索这一令人振奋的学科中的各种神奇之处。

热力学常常被人们认为是一门难学的学科，许多学生对它望而生畏。其实不然，因为热力学的原理是以我们的日常经验以及实验观察为基础的。这是一门成熟的基础学科，在此书中讨论到的内容都是众所确认的。问题只是“要知其然，还要知其所以然”，并要会使用。书中使用了更为有形的、直观的方法，常常将一些问题和学生们日常生活中的经历进行类比，这样他们可以将要学习的问题和他们已经知道的事情联系起来。

此教材不要求进行复杂的数学运算，只要求对基本的原理有清楚深入的理解，并掌握分析热力学问题的方法，以便能够理解、阐述、说明并解决复杂问题，得到正确的结果。此书正是有意识地努力引导学生朝此方向前进。

中等程度的学生能毫无困难地理解教材内容。它是面向学生，而不是超越学生的知识和能力进行讲述的。讲述由简单到一般，基本原理重复地应用于不同的系统，学生们可掌握如何应用这些原理，而不是只学会如何使用公式。因为热力学原理是基于实验的观察，因此本书中所有推导都是建立在有形的根据之上，使它们容易遵循和理解。事实上，此教材是可以自学的，这样就可以使教师解脱出来，更有效地利用课堂时间。

教材的叙述有着逻辑的次序。先是复习各种概念，然后准确地引出一些新的概念，以便为发展热力学原理打下坚实的基础。然后讨论纯物质的性质，使用了物性图表，以便形象地进行显示。此后引入理想气体的近似概念，同时还有关于其他气体的状态方程式。介绍了热和功之后，闭口系统的能量守恒原理就得出来了。接着就讨论流动功，进而得到控制容积的能量守恒原理，先是稳流系统，然后是一般的不稳定流系统。第二定律的叙述也遵循相同的次序，但特别强调熵的概念。关于可逆功以及损失等概念的得出，是先使用一些熟悉的例子，再将它们应用于较为复杂的工程系统中去。这样就把热力学的原理应用于工程的不同领域。

在教材的不同章节里，有一些例子和许多习题，其中包括一些扩展的设计题，融入了许多真

实世界中与热经济学有关的内容，如对不同的节能效果用美元值度量，使学生对能量的货币价值能有一定的认识。有的题还涉及对环境方面的影响，如污染物及温室气体进入大气所造成的影响，以提高学生的环境意识。

总结起来，本书具有如下特色：

1. 不强调系统相互作用时通常使用的热和功的符号传统，而是在讨论相互作用时，采用了基于平衡要求的直观的和统一的方法。鼓励学生在处理实际问题的过程中，首先确认系统，然后利用任何系统进行任何过程时的质量、能量、熵和 的平衡关系式，并对某一特定的问题，将这些平衡关系式加以简化。
2. 在解例题时，清楚地确定了系统，叙述了对本题特点的观察情况，作出了假设，并列举了合理假设的正当理由。同时保持非正式的谈话式的风格。
3. 此教科书将热力学的概念和学生们已经知道的事（如体重的增加、冷饮等）联系起来，使文章读起来饶有兴趣。增加了几个新的章节，讨论了一些实用的题目，如食物的冷藏和冻结、能量转换效率、家用冰箱以及在工业装置中降低压缩空气的成本，以显示热力学和工程实践以及日常生活的关系。
4. 在每一章中按专题将练习题归类，共约有 2000 道课堂练习题供选用，内容包括概念、设计及实验方面。还有许多题涉及现实的经济、设计及安全问题，可帮助学生提高对成本、工程实践及安全等的意识。
5. 本书附有 EES（工程问题题解）光盘并设有在线学习辅导中心。光盘内容有助于学生去解一些设计的题，并可提出一些“如果……，那会怎样”的问题。此软件还附带有一个方便用户使用的解题器和一些内装的资产表，它能使用户进行参数变化的研究以及最优化方面的研究，并将结果以表格或图形的形式显示出来。EES 光盘包含好几个项目，可以解此书的一些题，题上标有光盘记号以便易于识别。

本书基本代表了当前国际上最新的“工程热力学”教科书版本。可作为原版教材或教学参考书加以使用。

张冠忠
于北京

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注：前有*者为将于近期内推出的新书。

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¹ IE=International Edition

Thermodynamics is a funny subject. The first time you go through it, you don't understand it at all. The second time you go through it, you think you understand it, except for one or two points. The third time you go through it, you know you don't understand it, but by that time you are so used to the subject, it doesn't bother you anymore.

—Arnold Sommerfeld

There is nothing more practical than a good theory.

—L. Boltzmann

Knowledge and timber shouldn't be much used till they are seasoned.

—Oliver Wendell Holmes

The true scholar-educator becomes a sheep, not a bird. Passes on his knowledge selflessly. The sheep gives its lambs digested pure milk. The bird gives its chicks saliva-soaked feed.

—Said Nursi

Heat cannot, of itself, pass from a colder to a hotter body.

—Rudolf Clausius

Economic activities are inherently dissipative and governed by the second law of thermodynamics.

—Robert U. Ayres

All that is human must retrograde if it does not advance.

—Edward Gibson

Absence of occupation is not rest; a mind quite vacant is a mind distressed.

—William Cowper

There is no point at which having arrived we can remain.

(Author unknown)

The higher the level of expectation, the lower the level of satisfaction.

(Author unknown)

Blessed are those who expect nothing, for they will never be disappointed.

(Author unknown)

A science is any discipline in which the fool of this generation can go beyond the point reached by the genius of last generation.

—Max Gluckman

ABOUT THE AUTHORS

Yunus A. Çengel is a Professor of Mechanical Engineering at the University of Nevada, Reno. He received his Ph.D. in mechanical engineering from North Carolina State University in 1984. His current research areas are renewable energy, desalination, exergy analysis, and energy conservation. He served as the director of the Industrial Assessment Center (IAC) at the University of Nevada, Reno, from 1996 to 2000. He has led teams of engineering students to numerous manufacturing facilities in Northern Nevada and California to industrial assessments, and has prepared energy conservation, waste minimization, and productivity enhancement reports for them.

Dr. Çengel is also the author of the widely adopted textbooks *Introduction to Thermodynamics and Heat Transfer* (1997), *Heat Transfer: A Practical Approach* (1998), and *Fundamentals of Thermal-Fluid Sciences* (with Dr. Turner, 2001), all published by McGraw-Hill. Some of his textbooks have been translated to Chinese, Japanese, Korean, Spanish, Turkish, Italian, and Greek. Dr. Çengel is the recipient of several outstanding teacher awards, and he has received the ASEE Meriam/Wiley Distinguished Author Award for excellence in authorship in 1992 and again in 2000.

Dr. Çengel is a registered Professional Engineer in the State of Nevada, and is a member of the American Society of Mechanical Engineers (ASME) and the American Society for Engineering Education (ASEE).

Michael A. Boles is Associate Professor of Mechanical and Aerospace Engineering at North Carolina State University where he earned his Ph.D. in mechanical engineering and is an Alumni Distinguished Professor. Dr. Boles has received numerous awards and citations for excellence as an engineering educator. He is a past recipient of the SAE Ralph R. Teetor Education Award and has been twice elected to the NCSU Academy of Outstanding Teachers. On several occasions the ASME student section has recognized him as outstanding teacher and the faculty member having the most impact on mechanical engineering students.

Dr. Boles specializes in heat transfer and has been involved in the analytical and numerical solution of phase change and drying of porous media. He is a member of the American Society of Mechanical Engineers, the American Society for Engineering Education, and Sigma Xi. Dr. Boles received the ASEE Meriam/Wiley Distinguished Author Award in 1992 for excellence in authorship.

NOMENCLATURE

a	Acceleration, m/s^2	$\dot{m}$	Mass flow rate, kg/s
a	Specific Helmholtz function, $u - Ts$, kJ/kg	M	Molar mass, kg/kmol
A	Area, m^2	MEP	Mean effective pressure, kPa
A	Helmholtz function, $U - TS$, kJ	mf	Mass fraction
AF	Air-fuel ratio	n	Polytropic exponent
C	Speed of sound, m/s	N	Number of moles, kmol
C	Specific heat, $\text{kJ/kg} \cdot \text{K}$	P	Pressure, kPa
C_p	Constant pressure specific heat, $\text{kJ/kg} \cdot \text{K}$	P_{cr}	Critical pressure, kPa
C_v	Constant volume specific heat, $\text{kJ/kg} \cdot \text{K}$	P_i	Partial pressure, kPa
COP	Coefficient of performance	P_m	Mixture pressure, kPa
COP_{HP}	Coefficient of performance of a heat pump	P_r	Relative pressure
COP_R	Coefficient of performance of a refrigerator	P_R	Reduced pressure
d, D	Diameter, m	P_v	Vapor pressure, kPa
e	Specific total energy, kJ/kg	P_0	Surroundings pressure, kPa
E	Total energy, kJ	pe	Specific potential energy, gz , kJ/kg
EER	Energy efficiency rating	PE	Total potential energy, mgz , kJ
F	Force, N	q	Heat transfer per unit mass, kJ/kg
FA	Fuel-air ratio	$\dot{Q}$	Total heat transfer, kJ
g	Gravitational acceleration, m/s^2	$\dot{Q}$	Heat transfer rate, kW
g	Specific Gibbs function, $h - Ts$, kJ/kg	$\dot{Q}_H$	Heat transfer with high-temperature body, kJ
G	Total Gibbs function, $H - TS$, kJ	$\dot{Q}_L$	Heat transfer with low-temperature body, kJ
h	Convection heat transfer coefficient, $\text{W/m}^2 \cdot ^\circ\text{C}$	r	Compression ratio
h	Specific enthalpy, $u + Pv$, kJ/kg	R	Gas constant, $\text{kJ/kg} \cdot \text{K}$
H	Total enthalpy, $U + PV$, kJ	r_c	Cutoff ratio
$\bar{h}_c$	Enthalpy of combustion, kJ/kmol fuel	r_p	Pressure ratio
$\bar{h}_f$	Enthalpy of formation, kJ/kmol	R_u	Universal gas constant, $\text{kJ/kmol} \cdot \text{K}$
$\bar{h}_R$	Enthalpy of reaction, kJ/kmol	s	Specific entropy, $\text{kJ/kg} \cdot \text{K}$
HHV	Higher heating value, kJ/kg fuel	S	Total entropy, kJ/K
i	Specific irreversibility, kJ/kg	s_{gen}	Specific entropy generation, $\text{kJ/kg} \cdot \text{K}$
I	Electric current, A	S_{gen}	Total entropy generation, kJ/K
I	Total irreversibility, kJ	t	Time, s
k	Specific heat ratio, C_p/C_v	T	Temperature, $^\circ\text{C}$ or K
k_s	Spring constant	T_{cr}	Critical temperature, K
k_t	Thermal conductivity	T_{db}	Dry-bulb temperature, $^\circ\text{C}$
K_p	Equilibrium constant	T_{dp}	Dew-point temperature, $^\circ\text{C}$
ke	Specific kinetic energy, $V^2/2$, kJ/kg	T_f	Bulk fluid temperature, $^\circ\text{C}$
KE	Total kinetic energy, $mV^2/2$, kJ	T_H	Temperature of high-temperature body, K
LHV	Lower heating value, kJ/kg fuel	T_L	Temperature of low-temperature body, K
m	Mass, kg	T_R	Reduced temperature
		T_{wb}	Wet-bulb temperature, $^\circ\text{C}$

教师反馈卡

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PREFACE

OBJECTIVES

Thermodynamics is a basic science that deals with energy and has long been an essential part of engineering curricula all over the world. This introductory text contains sufficient material for two sequential courses in thermodynamics, and it is intended for use by *undergraduate* engineering students and by practicing engineers as a reference. The objectives of this text are

- To cover the *basic principles* of thermodynamics.
- 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.

GENERAL APPROACH

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.

The philosophy that contributed to the overwhelming popularity of the prior editions of this book has remained unchanged in this edition. 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 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 thermodynamics. The enthusiastic response we received from the users of prior editions—from small colleges to large universities—indicates that our objectives have largely been achieved.

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

NEW IN THIS EDITION

All the popular features of the previous editions are retained while new ones are added. With the exception of unifying the first law coverage and the addition of some new material, the main body of the text remains largely unchanged. The most significant changes in this edition are highlighted below.

Topics of Special Interest

Most chapters now contain a new section called “Topics of Special Interest” where interesting aspects of thermodynamics are discussed. Some existing sections such as *Thermodynamic Aspects of Biological Systems* in Chapter 1, *Refrigeration and Freezing of Foods* in Chapter 4, and *Second-Law Aspects of Daily Life* in Chapter 7 are moved to these sections as topics of special interest. New sections, such as *Saving Fuel and Money by Driving Sensibly* in Chapter 8 and *Chemical Potential and the Separation Work of Mixtures* in Chapter 12, are added. The topics selected for these sections provide intriguing extensions to thermodynamics, but they can be ignored if desired without a loss in continuity.



Comprehensive Problems with Extensive Parametric Studies

A distinctive feature of this edition is the incorporation of about 200 comprehensive problems that require conducting extensive parametric studies, using the enclosed EES (or other suitable) software. Students are asked to study the effects of certain variables in the problems on some quantities of interest, to plot the results, and to draw conclusions from the results obtained. These problems are designated by a computer icon for easy recognition, and can be ignored if desired. Solutions of these problems are given in the Instructor’s Manual.

Fundamentals of Engineering (FE) Exam Problems

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, about 200 new *multiple-choice problems* are added to 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.

Unified Coverage of the First Law of Thermodynamics

Now the first law of thermodynamics is covered in a single chapter (Chapter 4) using an intuitive energy balance relation that can be used for any kind of system undergoing any kind of process.

New Coverage of Energy and Environment

To address the growing concerns about the environment, a new section *Energy and Environment* is added to Chapter 1. In this section emissions (especially

from vehicles and power plants), air pollution, smog, acid rain, global warming, etc., and their relation to energy conversion processes are discussed.

Content Changes and Reorganization

With the exception of some fine-tuning, the main body of the text remains largely unchanged. The noteworthy changes in various chapters are summarized below for those who are familiar with the previous edition.

- In Chapter 1, the section on *Pressure* is revised and extended considerably. The section *Problem Solving Technique* is moved here for early coverage, with an overview of the EES software, and a new section *Energy and Environment* is added. The optional Topic of Special Interest in this chapter is *Thermodynamic Aspects of Biological Systems*.
- Chapter 2 now offers a more comprehensive coverage of thermodynamic properties, including specific heats of both ideal gases and incompressible substances. The section *Vapor Pressure and Phase Equilibrium* is moved to the end of chapter as the Topic of Special Interest.
- Chapter 3 now covers energy interactions by heat, work, and mass. A new section *Conservation of Mass Principle* is added here to provide complete coverage of mass balance. All references to gravitational work and accelerational work are deleted, and examples are done using changes in kinetic and potential energies. Also, the section *Modes of Heat Transfer* is moved to the end of the chapter as the Topic of Special Interest, making it easy to skip by those who desire to do so.
- Chapter 4 now introduces the first law of thermodynamics under one cover for all systems. It presents a unified approach to energy balance calculations. The optional Topic of Special Interest in this chapter is *Refrigeration and Freezing of Foods*.
- The following sections are moved to the end of chapters as the Topics of Special Interest for optional coverage: *Household Refrigerators* in Chapter 5, *Reducing the Cost of Compressed Air* in Chapter 6, *Second-Law Aspects of Daily Life* in Chapter 7, *Binary Vapor Cycles* in Chapter 9, *Thermoelectric Power Generation and Refrigeration Systems* in Chapter 10, and *Fuel Cells* in Chapter 14.
- Chapter 7 is revised, and the exergy content of flowing and nonflowing fluids is determined more directly using an intuitive approach.
- In Chapter 8, a new section *Saving Fuel and Money by Driving Sensibly* is added as a Topic of Special Interest to enhance awareness about fuel efficiency.
- In Chapter 12, a new section *Chemical Potential and the Separation Work of Mixtures* is added as a Topic of Special Interest for those who wish to study thermodynamic aspects of separation processes, with particular emphasis on desalination.
- In Chapter 14, discussions of fuels are expanded.
- In Appendices, the tables on fuel properties are replaced by more extensive ones.

LEARNING TOOLS

Emphasis on Physics

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

Presenting the Material in a Logical Order

The subject matter is covered in a logical order. First, various concepts are reviewed and some new ones are defined in order to establish a firm basis for the development of thermodynamic principles. Then the properties of pure substances are discussed and the use of property tables is illustrated. At this point the ideal-gas approximation is introduced, together with other equations of state, and the deviation from ideal-gas behavior is examined. Following a discussion of energy transfer by heat, work, and mass, the energy balance relation is developed and is applied to various systems. The concepts of entropy, exergy, and second-law efficiency are developed using familiar examples before they are applied to more complex engineering systems. The principles of thermodynamics are then applied to various areas of engineering.

Extensive Use of Artwork

Figures are important learning tools that help the students "get the picture." The text makes effective use of graphics. It contains more figures and illustrations than any other book in this category. Figures attract attention and stimulate curiosity and interest. Some 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 paragraph 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?

Chapter Openers and Summaries

Each chapter begins with an overview of the material to be covered and its relation to other chapters. A *summary* is included at the end of each chapter for a quick review of basic concepts and important relations.

Numerous Worked-Out Examples

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, with particular attention to the proper use of units. A sketch and a process diagram are included for most examples to clearly illustrate the geometry and the type of process involved.

A Wealth of Realistic End-of-Chapter Problems

The end-of-chapter problems are grouped under specific topics in the order they are covered to make problem selection easier for both instructors and students. The problems within each group start with 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. The problems under the *Design and Essay Problems* title 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. 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.

A Systematic Solution Procedure

A well-structured approach is used in problem solving while maintaining an informal conversational style. The problem is first stated and the objectives are identified, and the assumptions made are stated together with their justifications. Numerical values are used together with their units to emphasize that numbers without units are meaningless, and 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 Solutions Manual.

Physically Meaningful Formulas

The physically meaningful forms of the conservation 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:

$$m_{\text{in}} - m_{\text{out}} = \Delta m_{\text{system}}$$

Energy balance:

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

Entropy balance:

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

Exergy balance:

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

The relations above reinforce 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.

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.

A Choice of SI Alone or SI/English Units

In recognition of the fact that English units are still widely used in some industries, both SI and English units are used in this text, with an emphasis on SI. The material in this text can be covered using combined SI/English units or SI units alone, depending on the preference of the instructor. The property tables and charts in the appendixes are presented in both units, except the ones that involve dimensionless quantities. Problems, tables, and charts in English units are designated by “E” after the number for easy recognition, and they can be ignored easily by SI users.

Conversion Factors

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

SUPPLEMENTS

The following supplements are available to the adopters of the book.

Instructor's Solutions Manual

Available to instructors only, this manual features detailed solutions prepared using an equation editor complete with illustrations. The solutions are suitable for posting or using as handouts in class.

EES Software

Developed by Sanford Klein and William Beckman from the University of Wisconsin—Madison, this software program allows students to solve problems, especially design problems, and to ask “what if” questions. EES (pronounced “ease”) is an acronym for Engineering Equation Solver. EES is very easy to master since equations can be entered in any form and in any order. The combination of equation-solving capability and engineering property data makes EES an extremely powerful tool for students.



EES can do optimization, parametric analysis, and linear and nonlinear regression and provides publication-quality plotting capability. Equations can be entered in any form and in any order. EES automatically rearranges the equations to solve them in the most efficient manner. EES is particularly useful for thermodynamics problems since most of the property data needed for solving such problems are provided in the program. For example, the steam tables are implemented such that any thermodynamic property can be obtained from a built-in function call in terms of any two properties. Similar capability is provided for many organic refrigerants, ammonia, methane, carbon dioxide, and many other fluids. Air tables are built-in, as are psychrometric functions and JANAF table data for many common gases. Transport properties are also provided for all substances. EES also allows the user to enter property data or functional relationships with lookup tables, with internal functions written with EES, or with externally compiled functions written in Pascal, C, C++, or Fortran.

The *Student Resources CD* that accompanies the text contains the *Limited Academic Version* of the EES program and the scripted EES solutions of about 50 homework problems (indicated by the “EES” logo in the text). Each EES solution provides detailed comments and on-line help, and can easily be modified to solve similar problems. These solutions should help the student master the important concepts without the calculational burden that has been previously required.

Thermodynamics Tutorial

Also included on the *Student Resources CD* packaged free with the text is the *Interactive Thermodynamics Tutorial* developed by Edward Anderson of Texas Tech University. This tutorial allows students to further explore difficult topics such as Entropy and the Second Law of Thermodynamics.

Online Learning Center

Students and instructors using this book will have access to the text-specific Online Learning Center (OLC) at <http://www.mhhe.com/cengel-boles>. OLCs are the perfect solution for Internet-based content. These exclusive websites follow the text chapter by chapter and contain additional instructor and student supplements, including a Student Study Guide (developed by text co-author Michael Boles), FE Exam Review style quizzes, and instructional aids including Power Point Presentations.