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 philosophy that contributed to the warm reception of the first edition of this book has remained unchanged. 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. The enthusiastic response we received from the users of the first edition all over the world indicates that our objectives have largely been achieved.

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.

NEW IN THIS EDITION

All the popular features of the previous edition are retained while new ones are added. The main body of the text remains largely unchanged except that the coverage of forced convection is expanded to three chapters and the coverage of radiation to two chapters. Of the three applications chapters, only the *Cooling of Electronic Equipment* is retained, and the other two are deleted to keep the book at a reasonable size. The most significant changes in this edition are highlighted next.

EXPANDED COVERAGE OF CONVECTION

Forced convection is now covered in three chapters instead of one. In Chapter 6, the basic concepts of convection and the theoretical aspects are introduced. Chapter 7 deals with the practical analysis of external convection while Chapter 8 deals with the practical aspects of internal convection. See the Content Changes and Reorganization section for more details.

ADDITIONAL CHAPTER ON RADIATION

Radiation is now covered in two chapters instead of one. The basic concepts associated with thermal radiation, including radiation intensity and spectral quantities, are covered in Chapter 11. View factors and radiation exchange between surfaces through participating and nonparticipating media are covered in Chapter 12. See the Content Changes and Reorganization section for more details.

TOPICS OF SPECIAL INTEREST

Most chapters now contain a new end-of-chapter optional section called "Topic of Special Interest" where interesting applications of heat transfer are discussed. Some existing sections such as *A Brief Review of Differential Equations* in Chapter 2, *Thermal Insulation* in Chapter 7, and *Controlling Numerical Error* in Chapter 5 are moved to these sections as topics of special

interest. Some sections from the two deleted chapters such as the *Refrigeration and Freezing of Foods, Solar Heat Gain through Windows,* and *Heat Transfer through the Walls and Roofs* are moved to the relevant chapters as special topics. Most topics selected for these sections provide real-world applications of heat transfer, but they can be ignored if desired without a loss in continuity.


COMPREHENSIVE PROBLEMS WITH PARAMETRIC STUDIES

A distinctive feature of this edition is the incorporation of about 130 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 computer-EES and EES-CD icons for easy recognition, and can be ignored if desired. Solutions of these problems are given in the Instructor's Solutions Manual.

CONTENT CHANGES AND REORGANIZATION

With the exception of the changes already mentioned, the main body of the text remains largely unchanged. This edition involves over 500 new or revised problems. The noteworthy changes in various chapters are summarized here for those who are familiar with the previous edition.

- In Chapter 1, *surface energy balance* is added to Section 1-4. In a new section *Problem-Solving Technique,* the problem-solving technique is introduced, the engineering software packages are discussed, and overviews of EES (Engineering Equation Solver) and HTT (Heat Transfer Tools) are given. The optional Topic of Special Interest in this chapter is *Thermal Comfort.*
- In Chapter 2, the section *A Brief Review of Differential Equations* is moved to the end of chapter as the Topic of Special Interest.
- In Chapter 3, the section on *Thermal Insulation* is moved to Chapter 7, External Forced Convection, as a special topic. The optional Topic of Special Interest in this chapter is *Heat Transfer through Walls and Roofs.*
- Chapter 4 remains mostly unchanged. The Topic of Special Interest in this chapter is *Refrigeration and Freezing of Foods.*
- In Chapter 5, the section *Solutions Methods for Systems of Algebraic Equations* and the FORTRAN programs in the margin are deleted, and the section *Controlling Numerical Error* is designated as the Topic of Special Interest.
- Chapter 6, Forced Convection, is now replaced by three chapters: Chapter 6 *Fundamentals of Convection,* where the basic concepts of convection are introduced and the fundamental convection equations and relations (such as the differential momentum and energy equations and the Reynolds analogy) are developed; Chapter 7 *External Forced Convection,* where drag and heat transfer for flow over surfaces, including flow over tube banks, are discussed; and Chapter 8 *Internal Forced Convection,* where pressure drop and heat transfer for flow in tubes are

presented. *Reducing Heat Transfer through Surfaces* is added to Chapter 7 as the Topic of Special Interest.

- Chapter 7 (now Chapter 9) *Natural Convection* is completely rewritten. The Grashof number is derived from a momentum balance on a differential volume element, some Nusselt number relations (especially those for rectangular enclosures) are updated, and the section *Natural Convection from Finned Surfaces* is expanded to include heat transfer from PCBs. The optional Topic of Special Interest in this chapter is *Heat Transfer through Windows.*
- Chapter 8 (now Chapter 10) *Boiling and Condensation* remained largely unchanged. The Topic of Special Interest in this chapter is *Heat Pipes.*
- Chapter 9 is split in two chapters: Chapter 11 *Fundamentals of Thermal Radiation,* where the basic concepts associated with thermal radiation, including radiation intensity and spectral quantities, are introduced, and Chapter 12 *Radiation Heat Transfer,* where the view factors and radiation exchange between surfaces through participating and nonparticipating media are discussed. The Topic of Special Interest are *Solar Heat Gain through Windows* in Chapter 11, and *Heat Transfer from the Human Body* in Chapter 12.
- There are no significant changes in the remaining three chapters of *Heat Exchangers, Mass Transfer,* and *Cooling of Electronic Equipment.*
- In the appendices, the values of the physical constants are updated; new tables for the properties of saturated ammonia, refrigerant-134a, and propane are added; and the tables on the properties of air, gases, and liquids (including liquid metals) are replaced by those obtained using EES. Therefore, property values in tables for air, other ideal gases, ammonia, refrigerant-134a, propane, and liquids are identical to those obtained from EES.

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 author believes 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 motivating 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 heat transfer.

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.* Noting that the principles of sciences are based on experimental observations, 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 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.

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 WEALTH OF REAL-WORLD 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. The properties needed to solve the problem are listed separately. 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 Instructor's Solutions Manual.

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 appendices 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 the 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

These supplements are available to the adopters of the book.

COSMOS SOLUTIONS MANUAL

Available to instructors only.

The detailed solutions for all text problems will be delivered in our new electronic Complete Online Solution Manual Organization System (COSMOS). COSMOS is a database management tool geared towards assembling homework assignments, tests and quizzes. No longer do instructors need to wade through thick solutions manuals and huge Word files. COSMOS helps you to quickly find solutions and also keeps a record of problems assigned to avoid duplication in subsequent semesters. Instructors can contact their McGraw-Hill sales representative at http://www.mhhe.com/catalogs/rep/ to obtain a copy of the COSMOS solutions manual.

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 heat transfer 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 look-up 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 30 homework problems (indicated by the "EES-CD" 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 students master the important concepts without the calculational burden that has been previously required.

HEAT TRANSFER TOOLS (HTT)

One software package specifically designed to help bridge the gap between the textbook fundamentals and commercial software packages is *Heat Transfer Tools,* which can be ordered "bundled" with this text (Robert J. Ribando, ISBN 0-07-246328-7). While it does not have the power and functionality of the professional, commercial packages, HTT uses research-grade numerical algorithms behind the scenes and modern graphical user interfaces. Each module is custom designed and applicable to a single, fundamental topic in heat transfer.

BOOK-SPECIFIC WEBSITE

The book website can be found at www.mhhe.com/cengel/. Visit this site for book and supplement information, author information, and resources for further study or reference. At this site you will also find PowerPoints of selected text figures.

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Yunus A. Çengel