PREFACE TO THE FIRST EDITION

A major challenge facing the world today is not the depletion of energy resources, but the continual destruction of availability (the ability to produce useful work) predicted by the second law of thermodynamics. One of the primary objectives of this book is to develop second-law concepts in parallel with those of the first law to help make the student feel as comfortable with the concept of availability as with the more familiar concept of energy.

To fulfill this objective, the concept of the general balance,

Inflow + Produced = Outflow + Stored + Destroyed

is introduced in the first chapter and immediately applied to the extensive properties of mass, momentum, energy, availability, and entropy. Although at this stage the student is unable to measure energy, availability, and entropy, the student will accept that they are properties to be developed in later chapters. Early introduction to these balances, and continued reinforcement in later chapters, provides the student with a unified structure that aids immensely in problem solving.

Another unique feature is that the basic principles involving mass, momentum, energy, availability, and entropy are each stated as restrictions on the "produced" and "destroyed" terms in the general balance equation. If we ignore relativistic effects, as we do in classical thermodynamics, mass, momentum, and energy can never be produced or destroyed. The second-law statement in this book is that availability *destruction* must be greater than or equal to zero (availability is never produced). The second law in terms of entropy is that entropy *production* must be greater than or equal to zero (entropy is never destroyed). These principles, first introduced in Chapter 1, are reinforced throughout the book.

The development of the second law of thermodynamics differs from the usual approaches. Availability is developed as a system property at the *start* of the discussion of the second law (Chapter 4). By studying a battery or fuel cell and then a cylinder with piston, the student is given a physical feeling for nonuseful work (expansion energy to push aside the atmosphere). The application of availability balances is quite acceptable to the student who has already been exposed to balances in general in Chapter 1, to mass balances in Chapter 2, and to energy balances in Chapter 3. Balances of mass, energy, and availability then lead to the entropy balance.

Once the second law is developed, it is emphasized throughout the remainder of the book. In Chapter 5 (cycles) second-law analysis is considered to be equally as important as traditional first-law analysis. Availability destructions in various cycle components are calculated from second-law balances (availability or entropy) to show where are the most important needs for cycle improvement. Second-law cycle efficiency is introduced to evaluate performance.

Chapter 6 (nonreacting mixtures) includes both first- and second-law analysis on a more equal basis than that found in other textbooks. For moist-air problems at atmospheric pressure, other texts rely on the psychrometric chart (which does not have a second-law content). In this book, moist-air tables that include entropy are provided instead of the psychrometric chart so that entropy balances are now as convenient to make as energy balances.

Standardized properties are used for first- and second-law analyses of reacting mixtures in Chapter 7. Standardized enthalpies are derived from heat-transfer measurements and first-law energy balances; standardized entropies are calculated from the third law of thermodynamics.

The use of *reaction coordinates* to describe reacting mixtures when there are more unknown coefficients in a chemical equation than there are atom species to balance is another unique feature of this book. Equilibrium theory is developed with reaction coordinates to describe mixture composition. Property tables are included for 11 common reaction products. These tables have been expanded to include a normalized Gibbs function to facilitate equilibrium calculations. Students are shown how to apply equilibrium theory to consider such pollution problems as soot formation and the formation of oxides of nitrogen.

In the past, the rough notes of the professor had to be refined by cutting, pasting, and then retyping. This laborious process discouraged a polished product until after the second edition. Today, by virtue of the computer, the process of editing and revising a set of notes is much more practical. This text began its life some 10 years ago on a computer with relatively complete style, examples, and problems. At that time, illustrations were done by hand, but as software improved, the task was taken over by the computer. Through the years, the comments of colleagues and students allowed continual changes, with new "editions" produced about once a year. This evolution paid attention to student comments on readability, on type and abbreviation styles, and to their requests for space for notes. As a consequence, wide margins were introduced for student notes, and for text illustrations and diagrams to avoid disrupting the text descriptions.

The major goal of this book is to teach introductory and applied thermodynamics to junior-level students in engineering. The book is not intended to be a reference source for the experienced engineer since additional data are far too great to include in a teaching text. Also, an overabundance of topics or material would detract from the teaching objective. Orderly problem-solving techniques, systems, property diagrams, and balances are stressed. Other problems give the student practice in drawing graphs, interpolation, computer programming, and numerical integration.

Although engineers are in the midst of switching to the SI unit system, it is too early to use exclusively SI units since much engineering still employs US (English) units. Both SI and US (English) units are included throughout the text. Dimensions and units are discussed in Appendix A and unit equivalents are provided. Appendix B gives thermodynamic property data in US units. Appendix C gives comparable thermodynamic property data in SI units.

For the convenience of the student and the instructor, the property tables in appendixes B and C have been made into a separate booklet. With the booklet, students are not forced to switch back and forth between the homework problem in the text and the tables at the back of the book when working problems. Instructors may give closed-text exams that need these tables. The dimensional/unit relations in Tables A.3 through A.6 are also in the booklet. Since this booklet does not come with the text, it must be purchased separately if desired. Contact the author for more details.

An effort has been made to use notation familiar to students from calculus (*e.g.*, Δ notation, area function) and from mechanics (*e.g.*, $\mathbf{F} = M\mathbf{a}$, no g_c), and that will be consistent with later courses (*e.g.*, q for heat-transfer rate). In many thermodynamic books m is the symbol for the mass in a system and $\dot{m}$ is the symbol for the rate of mass flow across a system boundary. Except for the special case of a system with a single entering mass flow stream and no mass flow leaving, this conflicts with the widely accepted notation that $\dot{x} = dx/dt$. Thus, mf, not $\dot{m}$, is the symbol for mass-flow rate in this book.

Another feature of this textbook is the inclusion of over 50 carefully selected photographs to provide additional information about the size and scope of thermodynamic applications in the real world. Detailed captions for the photographs contain interesting engineering data to illustrate what might be in store for a student entering the energy area.

In summary, this book gives a comprehensive treatment of the most important topics and concepts in thermodynamics. It attempts to fit in with the student's background in calculus and mechanics. By discarding old approaches to the second law and placing more emphasis on second-law analysis, the student should gain a much better understanding of thermodynamics than is usually obtained from other books.

ACKNOWLEDGMENTS FOR THE FIRST EDITION

This book reflects my own experiences in learning and teaching thermodynamics. I have been influenced by my teachers when I was a student; J. W. Bursik, N. P. Bailey, and F. J. Bordt at Rensselaer Polytechnic Institute; and by A. L. London, W. C. Reynolds, R. H. Eustis, S. J. Kline, and F. Bloch at Stanford University; and by discussions with colleagues R. A. Gaggioli and E. F. Obert at the University of Wisconsin–Madison.

Professors W. A. Beckman, G. L. Borman, H. T. Ceylan, J. F. Davis, F. T. Elder, D. E. Foster, C. P. Gupta, S. A. Klein, J. W. Mitchell, P. S. Myers, H. N. Powell, K. W. Ragland, and O. A. Uyehara used early versions of this text in their classes and provided valuable feedback. A special word of thanks should also be given to the many students who asked questions when something was not clear or made constructive criticisms to improve the text for future students.

The notes for the book were originally developed on a mainframe computer at Wisconsin. M. F. Ganter and J. J. Uicker were especially kind in providing programming advice, computer time, and file space. J. I. Fritz and D. L. Oppriecht at the Madison Academic Computing Center were very helpful in reproducing countless sets of notes in time for classes. Figure labels and equations that were not convenient to do on the computer were expertly typed by L. L. Litzkow.

A major change in the production of the notes for the book was made in 1985 with the switch to the Apple Macintosh computer and the Apple LaserWriter. The text processor was Microsoft Word. Apple's MacDraw was used for the artwork. Art was added to the text files with Switcher and Multifinder.

Professors J. C. Bennett, Jr. (University of Connecticut), R. A. Gardner (Washington University), E. F. C. Somerscales (Rensselaer Polytechnic Institute), and E. M. Sparrow (University of Minnesota) provided valuable suggestions in the final review. I am also grateful for the comments of two anonymous reviewers.

The patience and understanding of my wife Susan and children Tim and Christy made late dinners and long nights and weekends of writing, drawing, proofreading, and editing more bearable.