Heat Transfer Applications for the Practicing Engineer

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To
Jack Powers

My friend,
a future basketball Hall-of-Famer,
and
a true quality individual

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Preface

We should be careful to get out of an experience only the wisdom that is in it—and stop there; lest we be like the cat that sits down on a hot stove-lid. She will never sit down on a hot stove-lid again—and that is well; but also she will never sit down on a cold one anymore.

Mark Twain (Samuel Langhorne Clemens 1835–1910),
Pudd'nhead Wilson, Chapter 19

This project was a rather unique undertaking. Heat transfer is one of the three basic tenants of chemical engineering and engineering science, and contains many basic and practical concepts that are utilized in countless industrial applications. The author therefore considered writing a practical text. The text would hopefully serve as a training tool for those individuals in industry and academia involved directly, or indirectly, with heat transfer applications. Although the literature is inundated with texts emphasizing theory and theoretical derivations, the goal of this text is to present the subject of heat transfer from a strictly pragmatic point-of-view.

The book is divided into four Parts: Introduction, Principles, Equipment Design Procedures and Applications, and ABET-related Topics. The first Part provides a series of chapters concerned with introductory topics that are required when solving most engineering problems, including those in heat transfer. The second Part of the book is concerned with heat transfer principles. Topics that receive treatment include steady-state heat conduction, unsteady-state heat conduction, forced convection, free convection, radiation, boiling and condensation, and cryogenics. Part Three—considered by the author to be the "meat" of the book—addresses heat transfer equipment design procedures and applications. In addition to providing a detailed treatment of the various types of heat exchangers, this part also examines the impact of entropy calculations on exchanger design, operation, maintenance and inspection (OM&I), plus refractory and insulation effects. The concluding Part of the text examines ABET (Accreditation Board for Engineering and Technology)-related topics of concern, including environmental management, safety and accident management, ethics, numerical methods, economics and finance, and open-ended problems. An appendix is also included. An outline of the topics covered can be found in the Table of Contents.

The author cannot claim sole authorship to all of the problems and material in this text. The present book has evolved from a host of sources, including: notes, homework problems and exam problems prepared by several faculty for a required one-semester, three-credit, "Principles II: Heat Transfer" undergraduate course offered at Manhattan College; I. Farag and J. Reynolds, "Heat Transfer", A Theodore Tutorial, East Williston, N.Y., 1994; J. Reynolds, J. Jeris, and L. Theodore, "Handbook of

Chemical and Environmental Engineering Calculations", John Wiley & Sons 2004, and J. Santoleri, J. Reynolds, and L. Theodore's "Introduction to Hazardous Waste Incineration", 2nd edition, John Wiley & Sons, 2000. Although the bulk of the problems are original and/or taken from sources that the author has been directly involved with, every effort has been made to acknowledge material drawn from other sources.

It is hoped that this writing will place in the hands of industrial, academic, and government personnel, a book covering the principles and applications of heat transfer in a thorough and clear manner. Upon completion of the text, the reader should have acquired not only a working knowledge of the principles of heat transfer operations, but also experience in their application; and, the reader should find himself/herself approaching advanced texts, engineering literature, and industrial applications (even unique ones) with more confidence. The author strongly believes that, while understanding the basic concepts is of paramount importance, this knowledge may be rendered virtually useless to an engineer if he/she cannot apply these concepts to real-world situations. This is the essence of engineering.

Last, but not least, I believe that this modest work will help the majority of individuals working and/or studying in the field of engineering to obtain a more complete understanding of heat transfer. If you have come this far, and read through most of the Preface, you have more than just a passing interest in this subject. I strongly suggest that you try this text; I think you will like it.

My sincere thanks are extended to Dr. Jerry Maffia and Karen Tschinkel at Manhattan College for their help in solving some of the problems and proofing the manuscript, and to the ever reliable Shannon O'Brien for her valuable assistance.

Louis Theodore

Introductory Comments

Prior to undertaking the writing of this text, the author (recently) co-authored a text entitled “Thermodynamics for the Practicing Engineer”. It soon became apparent that some overlap existed between thermodynamic and heat transfer (the subject of this text). Even though the former topic is broadly viewed as a science, heat transfer is one of the unit operations and can justifiably be classified as an engineering subject. But what are the similarities and what are the differences?

The similarities that exist between thermodynamics and heat transfer are grounded in the three conservation laws: mass, energy, and momentum. Both are primarily concerned with energy-related subject matter and both, in a very real sense, supplement each other. However, thermodynamics deals with the transfer of energy and the conversion of energy into other forms of energy (e.g., heat into work), with consideration generally limited to systems in equilibrium. The topic of heat transfer deals with the transfer of energy in the form of heat; the applications almost exclusively occur with heat exchangers that are employed in the chemical, petrochemical, petroleum (refinery), and engineering processes.

The aforementioned transfer of heat occurs between a hot and a cold body, normally referred to as the source and receiver, respectively. (The only exception is in cryogenic applications.) When this transfer occurs in a heat exchanger, some or all of the following 10 topics/subjects can come into play:

1. The class of heat exchanger
2. The physical surface arrangement of the exchanger
3. The quantity or rate of heat transferred
4. The quantity or rate of heat “lost” in the application
5. The temperature difference between the source and receiver
6. The prime mover(s) required in the application (e.g., pump, fan, etc.)
7. The entropy gain (i.e., the quality energy lost in the application)
8. The cost to design, construct, and start up a new application
9. The cost to operate the exchanger
10. The cost to maintain the exchanger

Each of the above topics receive treatment once or several times in this text.