FUNDAMENTALS OF HEAT EXCHANGER AND PRESSURE VESSEL TECHNOLOGY

J. P. Gupta

FUNDAMENTALS OF HEAT EXCHANGER AND PRESSURE VESSEL TECHNOLOGY

J. P. Gupta

Chemical Engineering Department
Indian Institute of Technology
Kanpur (U.P.), India

HEMISPHERE PUBLISHING CORPORATION

Washington New York London

DISTRIBUTION OUTSIDE NORTH AMERICA
SPRINGER-VERLAG

Berlin Heidelberg New York Tokyo

To my parents, Sh. Niader Mal and Smt. Kripa Dev
sisters, Pushpa, Krishna, and Suvira
wife, Prabha
children, Sonjai, Swati, and Jaideep

FUNDAMENTALS OF HEAT EXCHANGER AND PRESSURE VESSEL TECHNOLOGY

1 2 3 4 5 6 7 8 9 0 DODO 8 9 8 7 6 5

This book was set in Press Roman by Hemisphere Publishing Corporation. The editors were Roberta Robey, Maxine Langweil, and Brenda Brienza; the designer was Sharon DePass; the production supervisor was Miriam Gonzalez; and the typesetter was Sandra F. Watts.
R. R. Donnelley & Sons Company was printer and binder.

Library of Congress Cataloging in Publication Data

Gupta, J. P. (Jai Prakash)
Fundamentals of heat exchanger and pressure vessel technology.

Bibliography: p.
Includes index.
1. Heat exchangers. 2. Pressure vessels. I. Title.
TJ263.G86 1985 621.402'5 84-12865
ISBN 0-89116-344-1

DISTRIBUTION OUTSIDE NORTH AMERICA:
ISBN 3-540-15619-4 Springer-Verlag Berlin

PREFACE

Heat exchangers are the workhorse of industry. Variously known as condensers, coolers, evaporators, heaters, reboilers, vaporizers, and so forth, they are used extensively in chemical, fertilizer, petrochemical, petroleum, power, refrigeration, and other industries. With the current awareness and concern about energy and resource conservation as well as efficient and safe operation of plants, it is imperative that the heat exchangers be designed and operated optimally. Optimal design has become still more important as the size of heat exchangers continues to increase to take advantage of the economy of scale.

With the above in mind, I have taught a one-semester course on heat exchanger design at the Indian Institute of Technology, Kanpur, since 1976; I also taught it during the winter semester of 1983 at the University of Michigan, Ann Arbor. An abbreviated version has been used in short courses for practicing engineers in India and Argentina. During these courses, students have asked specific questions about thermal and mechanical designs, vibration analysis, and operation and maintenance of heat exchangers. Some questions were received by mail. The questions were compiled and many more were added (along with answers). The questions were then circulated among students in class and among leaders in academia and industry in India, the United Kingdom, and the United States. The responses received were very positive regarding both the usefulness of a book with a question-and-answer approach and the material covered in the questions.

The main advantage of a question-and-answer approach, which this book follows, is that it focuses the attention of the reader on a specific point, which facilitates learning the answer quickly since the reader's mind is not cluttered with much unrelated material, as in a conventional text.

Although the literature on heat exchangers is extensive and growing, a newcomer to the field confronts difficulties at a number of points and does not know where to turn since no one has enough time to answer all questions. Sometimes he or she is hesitant to ask "simple" questions. Until now, there was no single book that directly told a person about such items as tie-rods and various types of baffles; what to do if the calculated pressure drop is higher than the allowable value; comparison of various types of multi-pass exchangers, multiple segmental baffles, and tube layouts; effects of laminar and turbulent flows; minimum information required for thermal and mechanical design; flow stratification; when a stress anlaysis report is required and which factors are to be taken into account during a stress analysis; mechanical design and failure analysis; nondestructive testing methods; maintenance and repair; types of corrosion and fouling and steps to counter them; causes of vibration, vibrational damage and steps to prevent it; and so on.

This book is intended to help newcomers, those with a few years of experience in design and operation, and senior-level students in design courses find answers to over a thousand such questions. It is not meant for experts in the field, although they might use it to review information. The book is self-explanatory, self-contained, and easy to read. It brings out subtle details that do much to aid one's understanding of the topics.

As work on the book progressed, the scope of the topics covered was expanded. And so to keep this a reasonably sized volume, the actual thermal and mechanical design calculations have been left out. This decision was aided by two related factors. First, a number of books exist that deal with thermal design, while mechanical design is governed by codes and standards that are easy to follow. Second, in most industries the designers have access to in-house computer programs or those developed by cooperative research organizations, whose membership is continuously increasing. Hence, this book is not to be taken as a design book but one that would help a designer come up with better designs, in terms of both cost and performance, and an operator in understanding and controling the performance of a unit. In addition, this book is not meant to be an up-to-date and exhaustive literature survey of all the varied topics covered, since that would be impossible. It does cover much of the latest information available and gives over 540 references.

One drawback to using the question-and-answer approach is that the reader may unintentionally compare an answer with his or her own previous knowledge of the topic and become very critical of the answer given. It is hoped that readers who disagree with any of the answers in this book will contact the author so that improvements to the book can be made.

In an undertaking of this kind, some duplication of subject matter occurs. This has generally been handled by cross-referencing questions, figures, tables, and equations. In a cross-reference, the first number indicates the chapter number and the second indicates the question, figure, table, or equation number, as the case may be. There are over 680 such cross-references in this book.

Due to space restrictions, a number of questions and answers had to be deleted and the number of figures restricted. It is likely that some important questions have been missed altogether. Readers are encouraged to contact the author regarding any suggested questions they might have.

An author's experiences and training inevitably bias his or her treatment of topics chosen for inclusion in a book and this one is no exception. While direct-fired boilers, cooling towers, and fluidized bed combustors are outside the scope of this volume, the decision not to treat regenerators was a difficult one to make, it being a rather vast topic in itself. Some readers may find that some of their favorite topics are not dealt with in as much detail as others. Their indulgence is sought in communicating such topics to the author.

ACKNOWLEDGMENTS

This book has benefited greatly by the comments of my mentor, Professor Stuart W. Churchill, University of Pennsylvania, Philadelphia, and Dr. Krishna P. Singh, Joseph Oat Corp., Camden, New Jersey. They provided critical suggestions and encouragement and spent countless hours reading the manuscript.

Each chapter was reviewed by several internationally renowned experts in academia and industry. Their comments and criticism greatly improved the book. These individuals, as well as a few companies, are noted below:

B. D. Agarwal
M. Atkins
A. E. Bergles
B. C. Bhattacharyya
S. S. Biswas
D. Butterworth
T. C. Carnavos
S. S. Chen
S. W. Churchill
J. G. Collier
R. C. Conrad
A. Cooper
Jim Cunningham
Curwen and Newberry
Davy Powergas (India) Ltd.
P. Dayaratnam
M. J. Dholakia
K. Elayaperumal
N. Epstein
Pierre Le Goff
D. J. Gorman
O. P. Goyal
Hugh Goyder
Graphite Equipment Ltd.
B. N. Greene
G. F. Hewitt
A. Hussain
Kishore Jhalaria
A. E. Jones
M. V. Joshi
S. Kakaç
H. Kanoh
J. H. Kissler
P. C. Knott
Prashant Kumar
Linde A. G.
A. L. London
K. K. Mahajan
K. Marcinauskas
Jan Marriott
F. Mayinger
A. Moliterno
Y. Mori
A. C. Mueller
John S. Mueller
G. Muthukumarasamy
C. V. Ramakrishna
Sam A. Scaglione
S. N. Sengupta
B. H. Shah
R. K. Shah
S. Sideman
K. P. Singh
S. Sivasankaran
A. Slanciauskas
A. Stephen
Sulzer Brother Ltd.
V. Sundararajan
J. Taborek
V. J. Tennery
M. L. Vaidya
R. L. Webb
A. Žukauskas

The comments of two anonymous reviewers also proved quite helpful. Much encouragement and help also were provided, directly or indirectly, by Om Goyal, Dr. Virendra Bansal, Dr. D. N. Saraf, Mr. G. Stanko, Mr. N. K. Metia, Mr. S. Reginald, Yogendra Singh, Rajendra Sharma, my sisters Dr. Krishna Garg and Dr. Suvira Gupta, my wife Prabha, and children Sonjai, Swati, and Jaideep.

Mr. R. N. Srivastava, Mr. U. S. Misra, and Mr. B. S. Pandey typed and retyped several versions of the manuscript. The final version was typed by Ms. Cynthia Miller at the University of Michigan, Ann Arbor. The drawings were done by Mr. D. S. Panesar and Mr. D. K. Misra. Reproduction of drawings and associated work was done by Mr. D. Chakraborty and at the Graphic Arts, I.I.T., Kanpur, under the supervision of Mr. R. Mahesh and Mr. K. C. Kapoor.

Financial support was provided by the Quality Improvement Programme, Government of India, Ministry of Education and Social Welfare, at I.I.T., Kanpur. Use of necessary facilities at the University of Michigan was provided by the Chemical Engineering Department.

Several organizations gave permission to reproduce their copyrighted materials. These are acknowledged in the text. The following organizations permitted unlimited use of their publications without the need to seek permission for individual items: American Society of Mechanical Engineers, Hitachi-Zosen, Morgan Grampian Ltd., NALCO Chemical Co., Oak Ridge National Laboratory, and Patterson-Kelley Co. C. S. Enterprises, Publications Division, Delhi, granted complete freedom to reproduce over a hundred questions that appear (without answers) in my earlier book* and agreed to this summary acknowledgement.

Over the many years it took to write this book, and the unending changes that were made in the numerous drafts, the files for each chapter became thick and dog-eared and my memory started dimming. It is certain, therefore, that a few names are missing in the list of reviewers as well as a few acknowledgments for material used in this book. I beg the forgiveness of such people and organizations and wish to assure that it was not deliberate.

Both William Begell, president, and Mary Phillips Born, former editor-in-chief, of Hemisphere Publishing, were very helpful and generous in the publication of this book.

To all the individuals and organizations that helped me, I owe sincere thanks, and I feel a sense of deep gratitude toward them.

J. P. Gupta

*Gupta, J. P., *Heat Exchanger Design–A Practical Look,* 2d ed. C. S. Enterprises: Delhi, India. 1979.

NOTE ABOUT UNITS

Both SI and British units are used in this book. To a large extent, the general pattern follows the recommendations given in the *ASME Orientation and Guide for Use of SI (Metric) Units* (8th ed., ASME: New York, 1978). Generally, when an original source referred to in this book uses British units, the same units are used here, and the SI equivalents are given in parentheses, and vice versa. In several cases the conversions are not exact, and an engineering judgment about rounding off has been carefully made, in keeping with the recommendations of the above publication—for example, 34 ft = 10.4 m, instead of 10.3632 m. Furthermore, it is not implied that the material given in equivalent dimensions is standard and commercially available. For example, if a 2-in thickness is written as 51 mm, a flange of 51 mm thickness may not be a standard item.

CONTENTS

CHAPTER

ONE

SHELL-AND-TUBE HEAT EXCHANGERS—I: GENERAL

INTRODUCTION

● Shell-and-tube heat exchangers can handle a variety of services in a vast range of allowable design pressures and temperatures, from full vacuum to 6000 psig (41.5 MPa) and from cryogenic temperature to 2000°F (1100°C). Hence, these are the most versatile heat transfer equipment used in the process, power, and refrigeration industries.

In order to understand the design and operation of the shell-and-tube heat exchangers, it is important to know the nomenclature and terminology used to describe them and the various parts that go into their making. Only then can we understand without any anomaly, the design, communications, and reports on these units put out by researchers, designers, fabricators, and users.

Therefore, in this chapter we will introduce the nomenclature and parts of a shell-and-tube exchanger. This is the first chapter of a series discussing these units. Chapter 2 discusses the process (thermal) design without phase change, followed by Chapter 3, which covers the situations involving phase change. In the second half of this book we will discuss the mechanical design and other items related to some of the important parts of the exchangers discussed in this chapter.

NOMENCLATURE AND PARTS

1.1 How are the size and type of a heat exchanger designated?

TEMA Standards (Tubular Exchanger Manufacturers Assoc., 1978) and HEI Standards (Heat Exchange Institute, 1980) have specified the nomenclature for the size and type of a shell-and-tube heat exchanger. Those according to the TEMA Standards are given below, while the HEI Standards' nomenclature is discussed in the next question.

Size is designated by the nominal shell diameter and the tube length. In the British system of units, the nominal shell diameter is the inside diameter of the shell in inches rounded off to the nearest integer. However, for the kettle-type reboiler, the nominal port diameter precedes the nominal shell diameter. The tube length for a straight tube unit is the distance between the outermost tubesheet faces. For a U-tube unit, it is the distance between the outermost face of the tubesheet and the bend tangent, i.e., only the straight leg. In the SI and the metric system, all the dimensions are given in millimeters (mm). The type of the exchanger is designated by a set of letters associated with the front end, the shell, and the rear end as given in Fig. 1.1 and illustrated by the following examples.

1. Split-ring floating head (S) exchanger with removable channel and cover (A), single-pass shell (E), $23\frac{1}{4}$ in (590 mm) inside diameter with tubes 16 ft (4880 mm) long. Size 23-192 (590-4880), Type AES.
2. U-tube exchanger (U) with bonnet-type stationary head (B), split flow shell (G), 19 in (480 mm) inside diameter with tubes 7 ft (2130 mm) straight length. Size 19-84 (480-2130), Type BGU.
3. Fixed tubesheet exchanger with removable channel and cover (A), bonnet-type rear head (M), two-pass shell (F). $33\frac{1}{8}$ in (840 mm) inside diameter with tubes 8 ft (2440 mm) long. Size 33-96 (840-2440), Type AFM.

Special designs may be specified as best suits the manufacturer.

● In the discussion above, terms such as single-pass and two-pass shell have been used. These, respectively, mean that the shell-side fluid travels only once through the shell (single-pass) or twice, i.e., it enters at one end, travels to the other, and then returns to the end where it entered the shell (two-pass). Similarly, one can have multiple tube passes also. The number of tube passes is equal to or greater than the number of shell passes. In general, the multi-shell and tube passes are usually designated by two numerals separated by a hyphen, with the first numeral indicating the number of shell passes and the second numeral indicating the number of tube passes. Thus, a one-shell pass and two-tube pass AEL exchanger will be written as 1-2 AEL. It should be emphasized that this is not according to the TEMA Standards. They require the number of shell and tube passes to be spelled out as in the above examples. In a heat exchanger specification sheet (Q. 1.116), there is a separate space indicating the number of shell and tube passes.

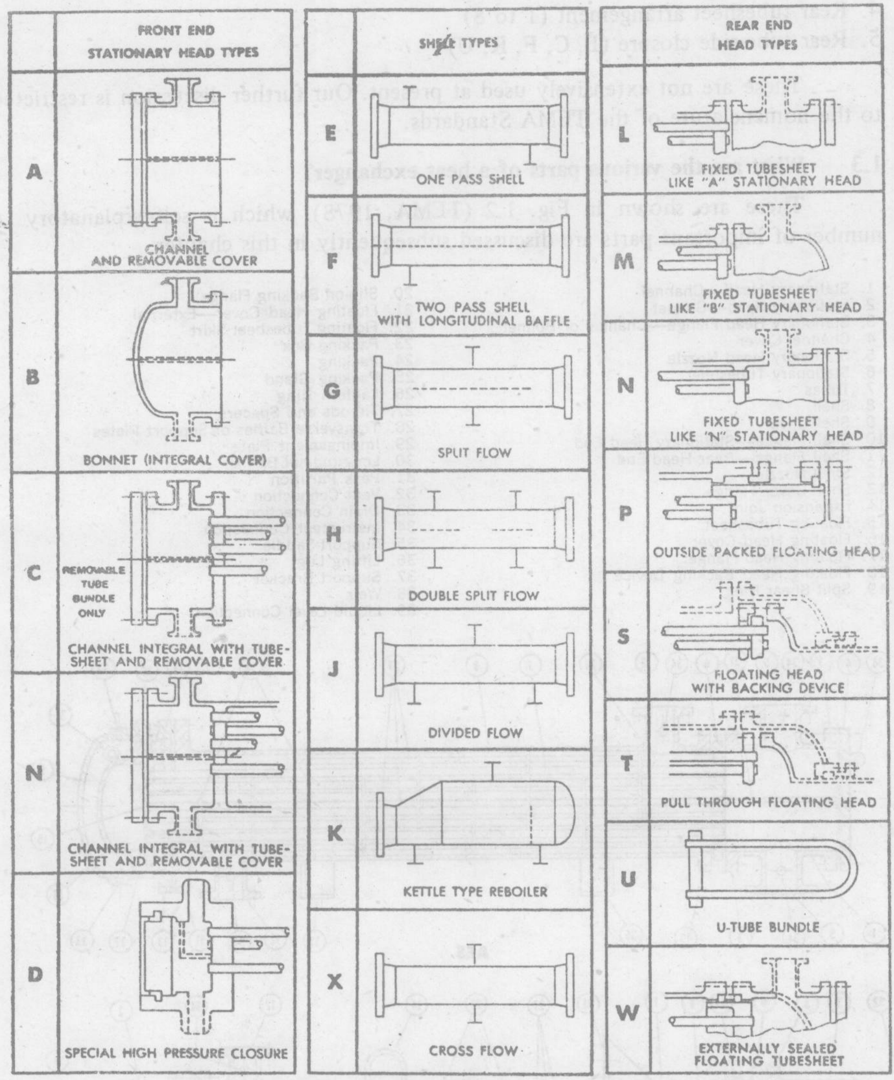

Figure 1.1 Heat exchanger nomenclature. *(© 1978 by Tubular Exchanger Manufacturers Association. All rights reserved.)*

1.2 How is the nomenclature specified by the HEI Standards (1980)?

These require five symbols to denote a heat exchanger as detailed below:

1. Front tube-side closure (symbols used: B, C, R)
2. Front tubesheet arrangement (1, 2, 3, 4)
3. Shell-side arrangement (S_1, S_2, S_d, S_k, S_s)