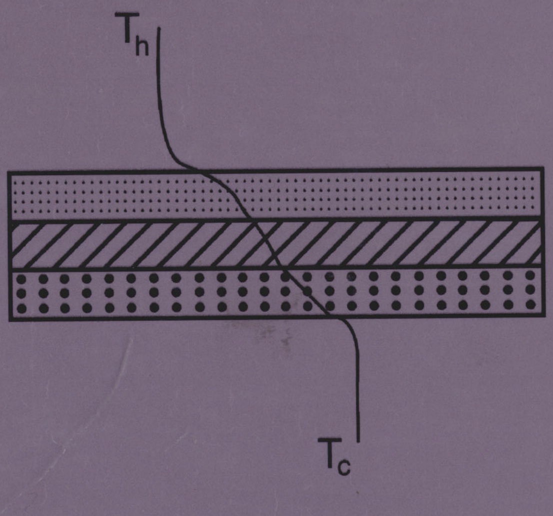
HEAT EXCHANGER DESIGN HANDBOOK



T. KUPPAN

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HEAT EXCHANGER DESIGN HANDBOOK

To my parents
Thulukkanam
Senthamarai

To my mentor
Dr. Ramesh K. Shah

Preface

A heat exchanger is a heat transfer device that exchanges heat between two or more process fluids. Heat exchangers have widespread industrial and domestic applications. Extensive technical literature is available on heat exchangers, but it is widely scattered throughout the technical journals, industrial bulletins, codes and standards, etc. This book is intended to consolidate into one volume the basic concepts of design and theoretical relationships useful in the design of heat exchangers, material selection, fabrication, and industrial practices.

Thermal design information such as heat transfer and pressure drop data, thermal design methods, and flow-induced vibration for exchangers involving single-phase flow duties are discussed. Other books and handbooks are available that deal with the design of vaporizers and condensers in which there is two-phase flow.

The book is an excellent resource for mechanical, chemical, and petrochemical engineers; process equipment and pressure vessel designers; and upper-level undergraduate and graduate students in these disciplines.

The book is divided into 15 chapters covering most of the information required for selection, design, material selection, fabrication, inspection, and operation of heat exchangers.

Chapter 1 discusses the classification and selection of heat exchangers for the intended application. In addition to the principal types used in industry, such as compact, shell and tube exchangers, regenerators, and plate heat exchangers, other specialized types such as double pipe, heat pipe, spiral, lamella, jacketing, glass, graphite, and Teflon heat exchangers are also discussed.

To successfully carry out the thermal design of heat exchangers, knowledge of thermohydraulic fundamentals is necessary. The discussion of thermal resistance variables, overall conductance equations, temperature distribution, mean temperature difference, temperature correction factors, number of transfer units, and effectiveness formulas for various flow arrangements, pass arrangements, and compact and shell heat exchangers with thermal relation charts is presented in Chapter 2.

Heat exchanger design methodology, heat exchanger design featuring rating and sizing problems, computer-aided thermal design, pressure drop analysis, temperature-dependent fluid properties correction, performance failures, flow maldistribution, and uncertainties involved in thermal design are covered in Chapter 3.

Compact heat exchangers are used in a wide variety of applications. The need for lightweight, space-saving, and economical heat exchangers has driven the development of compact surfaces. Basic construction types, surface geometrical parameters, j and f factors, fin efficiency, rating, and sizing are discussed in Chapter 4. Air coolers that use atmospheric air as the coolant are widely used in industry. They are also discussed in detail in Chapter 4.

Shell and tube sheet exchangers are the workhorses of process industries. The major construction features, thermal design, sizing, and rating are shown in detail in Chapter 5. Thermal design procedures for disk and doughnut and rod baffle heat exchangers are also discussed.

The drastic escalation of energy prices has made waste heat recovery more attractive over the past two decades. Recovery of waste heat from flue gas by means of heat exchangers can improve overall plant efficiency, serves to reduce national energy needs, and conserves fossil fuels. The objective of Chapter 6 is to acquaint the reader with various types of regenerators and with their construction details, their applications other than for heat recovery, and their thermal, and mechanical design. Additionally, some industrial regenerators for waste heat recovery are discussed.

In the 1930s, plate heat exchangers (PHEs) were introduced to meet the hygienic demands of the dairy industry. Today PHEs are universally used in many fields.They are used as an alternative to tube and shell exchangers for low- and medium-pressure liquid–liquid heat transfer applications. Design of PHEs, recent developments in their construction, and spiral plate heat exchangers are covered in Chapter 7.

In recent years, increasing energy and material costs have provided significant incentives for the development of various augmented heat transfer surfaces and devices. Various forms of enhancement devices are discussed in Chapter 8.

Most heat transfer processes result in the deposition of undesirable materials, commonly referred to as fouling. Fouling introduces perhaps the major uncertainty into the design and operation of heat exchangers, very often leading to extra capital and running costs, and reduces thermal performance. This necessitates a thorough understanding of the fouling phenomenon. Fouling mechanisms, prevention, and control are reviewed in Chapter 9.

One of the major considerations in the design of shell and tube heat exchangers is that it is free from flow-induced vibration problems. Flow-induced vibration can cause potential tube failures. Chapter 10 presents a review of flow-induced vibration mechanisms, their evaluation, and vibration prevention guidelines.

Chapter 11, on the mechanical design of shell and tube heat exchangers, deals with minimum thickness calculation procedures and stress analysis of various pressure parts such as tubesheets, heads, end closures, flanges, expansion joints, and nonpressure parts. Tubesheet design, as per ASME code, TEMA, BS 5500, and CODAP, is explained in detail. Important details of heat exchanger and pressure vessel construction codes and standards are also covered in detail.

Metallic corrosion is a process that causes enormous material losses annually. Thus it is necessary to examine thoroughly the material and environmental interactions that adversely affect the performance and life of equipment. Chapter 12 discusses corrosion principles, various forms of corrosion and their evaluation, corrosion control and prevention, and monitoring. With few exceptions, water is the preferred industrial medium for removing heat from process fluids. An understanding of cooling-water corrosion is important for heat exchanger designers. Most problems associated with cooling water are identified, and their control and prevention are also discussed.

Proper material selection is important for desired thermal performance, strength considerations, safe operation, and achieving the expected life and economy. Thus it is necessary to have a thorough knowledge of various heat exchanger materials and their fabricability. Chapter 13 discusses the selection criteria for a wide spectrum of heat exchanger materials and their fabrication by welding.

Quality of goods and equipment manufactured in the world market has become a matter of concern in recent years. For heat exchangers and pressure vessels, the overriding goal is to avoid the consequences of failure, which can be catastrophic in human, monetary, and environmental terms. Chapter 14 discusses various aspects of quality control and quality assurance, inspection, and nondestructive testing methods (NDT) and recent trends in NDT techniques.

After thermal design, the heat exchanger unit is fabricated by shop floor operations. Beyond the theoretical background, a knowledge of shop floor practices is required for a manufacturer to efficiently achieve the desired quality and performance. Chapter 15 discusses various shop floor practices for shell and tube heat exchangers, and brazing and soldering of compact heat exchangers.

The preparation of this book was facilitated by the great volume of existing literature contributed by many workers and scholars in this field. I have tried to acknowledge all the sources and have sought the necessary permissions. If omissions have been made, I offer my sincere apologies. Most materials manufacturers and research organizations responded to my inquiries and supplied substantial useful data and informative material. They are all acknowledged either directly or through references. Last, I make a special mention of my mentor and guide Dr. R. K. Shah, Vice President, ASME Board on Communications, Delphi Harisson Thermal Systems, Lockport, New York, who helped me throughout the preparation of the book and provided the basic literature required for the thermal design, flow-induced vibration, and thermal relations formulas for all types of arrangements.

During the preparation of this book, my parents and family were denied much of my time and interest that they rightfully deserve. I apologize to them.

T. Kuppan

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Heat Exchangers—Introduction, Classification, and Selection

1 INTRODUCTION

A heat exchanger is a heat-transfer devise that is used for transfer of internal thermal energy between two or more fluids available at different temperatures. In most heat exchangers, the fluids are separated by a heat-transfer surface, and ideally they do not mix. Heat exchangers are used in the process, power, petroleum, transportation, air conditioning, refrigeration, cryogenic, heat recovery, alternate fuels, and other industries. Common examples of heat exchangers familiar to us in day-to-day use are automobile radiators, condensers, evaporators, air preheaters, and oil coolers. Heat exchangers could be classified in many different ways.

2 CONSTRUCTION OF HEAT EXCHANGERS

A heat exchanger consists of heat-exchanging elements such as a core or matrix containing the heat-transfer surface, and fluid distribution elements such as headers or tanks, inlet and outlet nozzles or pipes, etc. Usually, there are no moving parts in the heat exchanger; however, there are exceptions, such as a rotary regenerator in which the matrix is driven to rotate at some design speed. The heat-transfer surface is in direct contact with fluids through which heat is transferred by conduction. The portion of the surface that separates the fluids is referred to as the primary or direct contact surface. To increase heat-transfer area, secondary surfaces known as fins may be attached to the primary surface.

3 CLASSIFICATION OF HEAT EXCHANGERS

In general, industrial heat exchangers have been classified according to (1) construction, (2) transfer processes, (3) degrees of surface compactness, (4) flow arrangements, (5) pass arrangements, (6) phase of the process fluids, and (7) heat-transfer mechanisms. These classifications (shown in Fig. 1) are briefly discussed here. For more details on heat exchanger classification and construction refer to Shah [1,2], Gupta [3], and Graham Walker [4]. For classification and systematic procedure for selection of heat exchangers, refer to Larowski et al. [5a,5b].

3.1 Classification According to Construction

According to constructional details, heat exchangers are classified as [1]:

1. Tubular heat exchangers—double pipe, shell and tube, coiled tube
2. Plate heat exchangers—gasketed, spiral, plate coil, lamella
3. Extended surface heat exchangers—tube-fin, plate-fin
4. Regenerators—fixed matrix, rotary

Tubular Heat Exchanger

Double Pipe Exchangers. A double pipe heat exchanger has two concentric pipes, usually in the form of a U-bend design as shown in Fig. 2. The flow arrangement is pure countercurrent. A number of double pipe heat exchangers can be connected in series or parallel as necessary. Their usual application is for small duties requiring, typically, less than 300 ft^2 and they are suitable for high pressures and temperatures, and thermally long duties [5]. This has the advantages of flexibility since units can be added or removed as required, and the design is easy to service and requires low inventory of spares because of its standardization. Either longitudinal fins or circumferential fins within the annulus on the inner pipe wall are required to enhance the heat transfer from the inner pipe fluid to the annulus fluid. Design pressures and temperatures are broadly similar to shell and tube heat exchangers. The design is straightforward, and carried out using the method of Kern [6], or proprietary programs.

Shell and Tube Heat Exchanger. In process industries, shell and tube exchangers are used in great numbers, far more than any other type of exchanger. More than 90% of heat exchangers used in industry are of the shell and tube type [7]. The shell and tube heat exchangers are the "work horses" of industrial process heat transfer [8]. They are the first choice because of well-established procedures for design and manufacture from a wide variety of materials, many years of satisfactory service, and availability of codes and standards for design and fabrication. They are produced in the widest variety of sizes and styles. There is virtually no limit on the operating temperature and pressure.

Coiled Tube Heat Exchanger.

Coiled Tube Heat Exchanger Used for Liquefaction Systems. One of the three classical heat exchangers used today for large-scale liquefaction systems is the coiled tube heat exchanger (CTHE). The construction details are explained in Refs. 5 and 9. Construction of these heat exchangers involves winding a large number of small-bore ductile tubes in helix fashion around a central core tube, with each exchanger containing many layers of tubes along both the principal and radial axes. Tubes in individual layers or groups of layers may be brought together into one or more tube plates through which different fluids may be passed in counterflow to the single shellside fluid.

The high-pressure stream flows through the small-diameter tubes, while the low-pressure return stream flows across the outside of the small-diameter tubes in the annular space between the inner central core tube and the outer shell. Pressure drops in the coiled tubes are equalized for each high-pressure stream by using tubes of equal length and varying the spacing of these in the different layers. Because of small-bore tubes on both sides, CTHEs do not permit mechanical cleaning and therefore are used to handle clean, solid-free fluids or fluids whose fouling deposits can be cleaned by chemicals. Materials are usually aluminum alloys for cryogenics, and stainless steels for high-temperature applications.

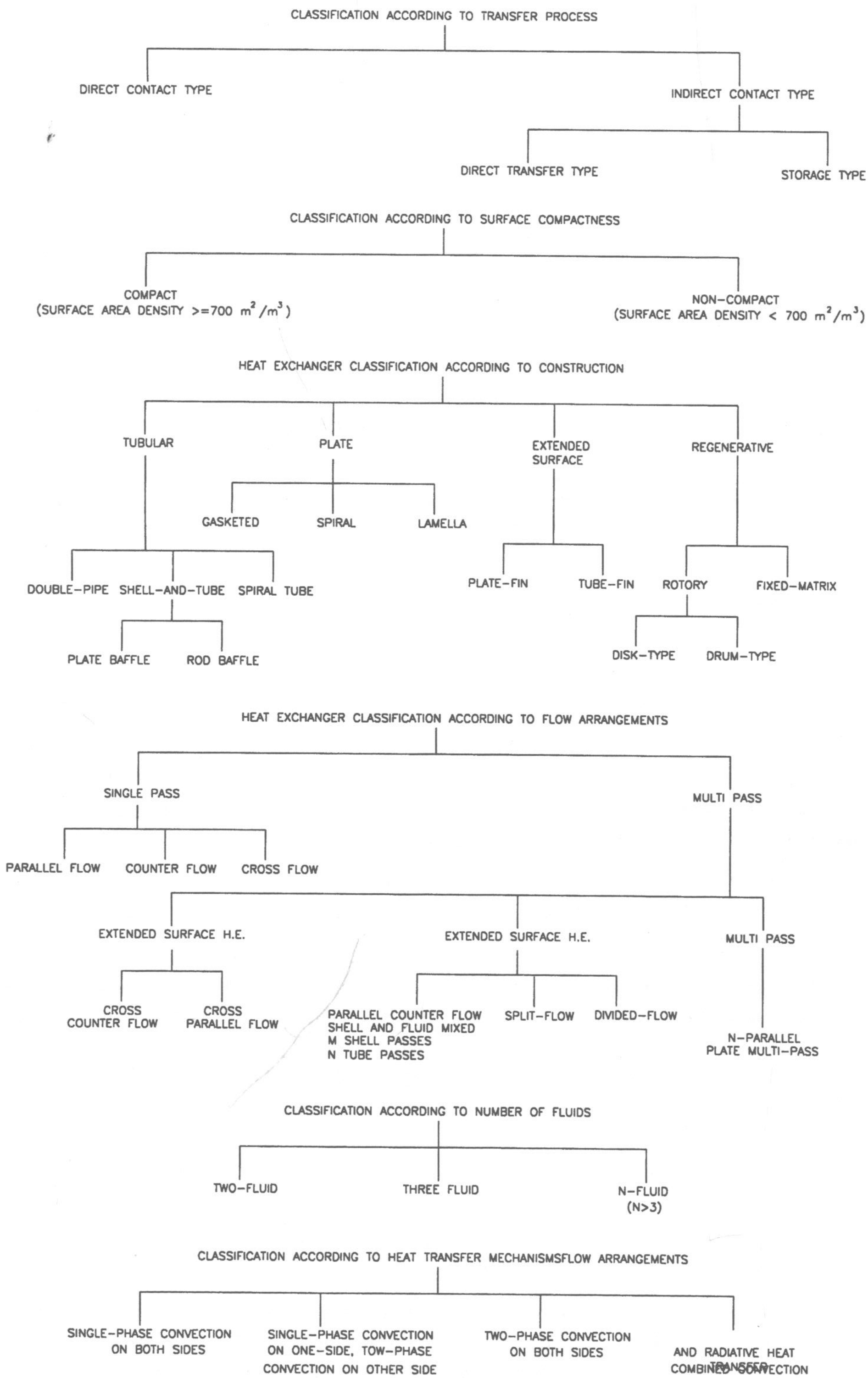

Figure 1 Classification of heat exchangers [1].