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R. Mukherjee Practical Thermal Design of Shell-and-Tube Heat Exchangers

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by

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Dedication

To the memory of my parents, who taught me to believe in myself

To my wife, Kalpana, for her unflagging patience and support

To my daughter, Shilpi, and my son (-in-law), Bappa, for their faith and conviction

Finally, to the reader, who made the entire effort worthwhile

Acknowledgments

I am indebted to Almighty God for having given me the education, intelligence, opportunity, strength, and fervor to write this book.

I am also indebted to all those from whom I learned heat exchanger design over the years. I regret it is not possible to recount their names individually for the simple reason that it would be too long a list!

Without the encouragement and support of Cynthia Mascone, presently Technical Editor at Chemical Engineering Progress, and her peer Gail Nalven, I would never have started writing the book!

This book might not have been possible without the wonderful exposition of heat exchanger technology by Heat Transfer Research, Inc. (HTRI). My long experience in the field of heat exchangers has been very largely honed on the platform of HTRI whose software I have been using since 1974.

Nobody can write a book on shell-and-tube heat exchangers without sourcing from the Standards of Tubular Exchanger Manufacturers Association (TEMA), and I am no exception.

I am grateful to HTRI, Begell House, Cal Gavin, AIChE, TEMA, ABB Lummus Heat Transfer, Brown Fintube, UOP, Alfa Laval and Heatric for some of the diagrams and photographs used in this book that have been duly acknowledged where they appear.

I will always be indebted to Bill Begell at Begell House for deciding to publish this book.

How can I forget my good friend Graham Polley? It was he who led me to Bill in the first place.

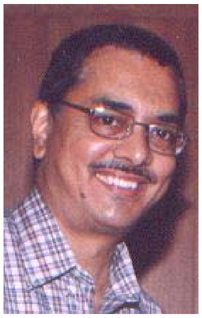
I am grateful to Janet Rogers at Begell House for managing my book, Donna Thompson at MessagePros for undertaking the arduous task of copyediting my book and doing it with aplomb, and all those at Begell House who were responsible for the production of this book.

What we are able to accomplish in our lives, whether professionally or otherwise, is the result of the Lord's grace and the encouragement and support we receive from myriad sources. This book is therefore truly a collaborative effort, and the credit belongs to the human fraternity at large rather than to any individual.

About the Author

R. Mukherjee is a consultant in unfired heat transfer based in New Delhi, India. He has over 33 years of experience in the thermal design, revamping and troubleshooting of air-cooled and shell-and-tube heat exchangers, and considerable experience in the design of heat exchanger networks. He has written several articles and presented many papers at technical symposia. Mukherjee has also served as faculty for numerous courses on heat exchanger design and operation, energy conservation, and heat exchanger networks, and presently teaches an intensive two-day in-house refresher course in the design and operation of heat exchangers that can be offered at any plant or office location around the world. He is an honors graduate in chemical engineering from Jadavpur University, Calcutta, India.

In his spare time, Mukherjee enjoys reading (Kahlil Gibran is a big favorite), writing, listening to music and collecting quotations. He lives in New Delhi with his wife, Kalpana. Their daughter, Shilpi, and her husband, Bappa, live in Illinois, with their baby son, Sohum.



R. Mukherjee

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PREFACE

When I was a young boy in school, I longed to be a doctor but fate deemed otherwise and I ended up becoming a chemical engineer. Now chemical engineering, like all other fields, is a very vast field but I ended up in the very narrow specialization of thermal design of shell-and-tube and air-cooled heat exchangers. I must confess that after eight to ten years of this activity, my soul yearned for a change and I sought to diversify into the world of fired heaters. However, for various reasons, this did not materialize and I continue to rove the world of unfired heat transfer. After a period of another five years, I found my interest in heat exchangers rekindled, thanks to the wonderful exposition of this technology by HTRI (Heat Transfer Research, Inc.). Pinch technology came of age around that time and proved to be a perfect foil and adjunct to heat exchanger thermal design.

I have always been inspired by these words of George Eliot: “What do we live for if not to make the world less difficult for each other?” Buoyed by a positive frame of mind, I thought that it might be a good idea to share some of the things that I had learned with readers across the world and started writing an odd paper or two for journals such as *Chemical Engineering Progress* and *Hydrocarbon Processing*. A major accident left me severely handicapped and curtailed my mobility drastically. This proved to be a blessing in disguise as far as my literary prowess was concerned. With a lot of time on my hands and a PC at home, I wrote a few comprehensive papers for *Chemical Engineering Progress* and *Hydrocarbon Processing* and received some very appreciative and heartening feedback. This gave me the confidence that I could now write a full-fledged book, an idea that Ms. Cynthia Mascone, presently Technical Editor at *Chemical Engineering Progress*, supported keenly.

My desire to write this book was precipitated by the absence of such a book. Recent heat exchanger design literature has been predominantly occupied by proceedings of conferences. There is no book on the market that explains the logic of heat exchanger thermal design and gives practical suggestions, recommendations, and real-life case studies for actually designing industrial heat exchangers. So I decided to write just such a book.

The theoretical aspects of single-phase heat transfer, condensation, and vaporization have been presented very well in several books. So what was really required was a practical “how to design” book with numerous worked-out examples or case studies to embellish or illustrate a particular technique, facet, or style of design. The thousands of heat exchanger designs that I have been associated with over the last 33 years provided numerous such opportunities. They say that one picture is more eloquent than a thousand words. If you extend this logic, one appropriate illustration by a case study is more eminently didactic than a long dissertation on a particular subject as a case study leaves nothing to the imagination.

Throughout the book, therefore, carefully-chosen examples are presented at strategic locations so that the reader will have a clear understanding of the subject matter being discussed.

While working with HTRI software, I have always tried to observe the interplay of parameters and a basic understanding of cause and effect. I have also always attempted to understand why things happen the way they do. For example, why do viscous liquids behave so poorly inside tubes? Why does putting shells in series reduce the penalty due to temperature profile distortion? Why is flow-induced vibration really a pressure drop problem? And so on. While working on designs, I have always asked myself, “Isn’t there a better way of doing this?” Such an attitude has helped immensely in improving the quality of the designs and I exhort all designers to adopt a similar attitude.

This book has therefore been written primarily for the heat exchanger thermal designer. But I am confident that it will be useful to process engineers as well, a significant part of whose routine job is to specify heat exchangers. Since operating aspects are also often discussed, I trust it will be of interest to plant operation specialists as well.

Last but not least, it is my fond hope that even undergraduate chemical and mechanical engineering students will find it interesting, informative, and useful. I still remember that when I was an undergraduate student, I used to long for more practical, real-life information about industrial practice. If one considers that many engineering graduates end up working in the chemical process industries, there may be a lot of merit in adding such a flavor to heat transfer in the university curriculum, as indeed it is to all other fields of human learning. The juxtaposition of industrial equipment design practice with basic theory will go a long way in making the subject more meaningful.

Being the first book I have written, there is bound to be significant scope for improvement. I will be very grateful to anyone offering positive guidance on shortcomings as well as inaccuracies.

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CHAPTER 1

Introduction

Shell-and-tube heat exchangers (STHEs) in their various manifestations are undoubtedly the most widely and commonly used unfired heat transfer equipment in the chemical processing industries. They are also used extensively in coal- and gas-based, nuclear, ocean thermal, and geothermal power generation facilities.

Although strongly challenged by the plate heat exchanger in recent years, the STHE still remains the undisputed leader in the arena of heat exchangers. The reasons for this are manifold:

1) STHEs are very flexible in size and can vary from less than one square meter to a thousand square meters and even more.
2) They are mechanically robust to withstand normal shop fabrication stresses, the rigors of transportation and erection, as well as the stresses of normal and abnormal operating conditions.
3) They can be cleaned relatively easily. Both mechanical as well as chemical cleaning programs can be employed.
4) The components that are most liable to failure—tubes and gaskets—can be replaced easily.
5) Good thermal and mechanical design methods are widely available.
6) A very wide fabrication base is available globally.

Besides, the development of tube inserts, helical baffles, and twisted tubes promises to make the STHE even more superior as these eliminate some of the inherent shortcomings of STHEs.

Evidently, since the STHE is the oldest model of the heat exchanger, it has a well-established methodology [1–5]. Until the late 1970s and early 1980s, this knowledge was not esoteric but was widely understood. However, with the development of the shellside stream analysis model and the subsequent advent of the personal computer and tremendous computing speeds, powerful software for the thermal design of STHEs gradually evolved. Today, several very sophisticated software packages are available for the thermal design of STHEs, a task now carried out by engineering contractors, fabricators, and operating companies all over the world, representing a wide global fraternity. Since these software packages are very user-friendly as well, it is now very convenient to optimize and produce a near-perfect design for a given application.

However, with the availability of such superior software, there has been an undue dependence on the software and much of the basic understanding of thermal design has been lost. In other words, these software packages are often employed as "black boxes" without the designer being truly in control of the design process and understanding the nuances of design. It must be appreciated that software is only a tool and with any sophisticated software, a proper and sound understanding of the fundamental principles and interplay of parameters is essential in order to exploit it successfully for producing an optimum design. The principal purpose of writing this book is to help the heat exchanger thermal designer attain such an understanding.

As *example is better than precept*, several case studies are presented in this book in order to vividly bring out a particular methodology, principle, or practice that has been advocated.

The design of STHEs comprises two distinct activities, viz., thermal design and mechanical design. In thermal design, the basic sizing of the heat exchanger is accomplished. That is to say, parameters such as the number, outer diameter, thickness and length of tubes, tube pitch, number of tube passes, shell diameter, baffle spacing and cut, nozzle sizes, and some other construction details are frozen. In the subsequent activity of mechanical design, the thicknesses and precise dimensions of the various components are determined and a bill of materials produced. Detailed engineering drawings are prepared based upon which actual fabrication drawings are made. In this book, as the title suggests, we shall talk principally about thermal design.

Presently there is no book available on “practical” shell-and-tube heat exchanger thermal design. The books that are available dwell heavily or fully on the theoretical aspects of unfired heat transfer as they are applicable to shell-and-tube heat exchangers. If they carry worked-out examples, these are very simplistic and certainly not comparable to what the commercial software designers employ for carrying out real-life designs. The present book is based upon the author’s experience of 32 years in the design of heat exchangers for the oil refineries and chemical process industries and mirrors many real-life situations, which were far from straightforward. All these experiences have been put together in a structured, focused, logical, and didactic manner and special effort has been made at bringing out the interplay of parameters for a thorough understanding of basic issues.

Now, we come to the individual chapters themselves. Chapter 2, “Classification of shell-and-tube heat exchangers,” gives a detailed rundown of the various components and constructional features of STHEs, as a good understanding of these is vital to the thermal design of this equipment. For example, the thermal engineer must be very familiar with the various components and their relationship, know when to use which type of STHE and be aware of the clearances between various components, some of which are crucial. As such, this chapter will be of considerable interest to mechanical designers of STHEs as it explains the implications of several constructional features on thermal design.

Chapter 3, “Thermal design and its optimization: single-phase heat exchangers,” is a very important chapter as it discusses various basic features which are relevant not just to single-phase heat exchangers, but to condensers and reboilers as well. Shellside stream analysis and the consequent temperature profile distortion with its associated penalty factor are explained at length. These are very basic concepts which form much of the foundation of knowledge for heat exchanger design. The simultaneous optimization of shellside and tubeside calculations is certainly not an easy task. With so many parameters (such as type of shell, baffling, tube pitch, and tube layout pattern), shellside optimization is itself quite complex. However, with the help of logical explanation, arguments, and case studies, the design methodology is made easy to understand and apply. The selection of shell and/or baffling styles for the progressive reduction of shellside pressure drop is brought out in a clear, step-by-step method.

Chapter 4 is entitled, “Mean temperature difference.” After discussing fundamental issues of co-current and countercurrent flow, it progresses to a combination of the two and the resultant F_t correction factor. It discusses temperature cross, the use of multiple shells in series, and the determination of F_t for various situations. Finally it discusses shellside temperature profile distortion and its associated penalty on the MTD of a heat exchanger. A case study demonstrates how and when to reduce this penalty factor by the use of multiple shells in series, even when there is no temperature cross.

The allocation of sides, that is, which stream should be allocated to the shellside of an STHE and which stream to the tubeside, is often not a straightforward process. The several parameters that influence the selection process are discussed in considerable detail in Chapter 5, "Allocation of sides: shellside and tubeside." A case study guides the reader through the selection process.

Chapter 6 is on the "Methodology of the use of multiple shells." Multiple shells are often required to be used either in series or in parallel (or in a combination thereof). In some extreme situations, one side (say, the shellside) is connected in series while the other side (in this case, the tubeside) in parallel. This chapter, embellished by two case studies, explores in detail the methodology of selection of multiple shells. Among other things, it is clearly brought out that multiple shells in series are not just used for "temperature cross" situations, but also to utilize allowable shellside pressure drop fully, and often result in a lower first cost when compared to a single-shell design.

So far, the book has dwelt on the thermal design of single-phase STHEs. We now move over to services and applications involving phase change. Chapter 7, "Thermal design of condensers," is a comprehensive elaboration of this subject. After a brief classification of condensers according to various construction and service parameters and a brief account of the mechanisms of condensation, the chapter comes to its real intent: practical guidelines for thermal design. These include the determination of shell style and baffling, the use of multiple shells, the handling of desuperheating and subcooling, nozzle sizing, and handling of condensing profiles and physical property profiles. Low pressure condensing, the use of low-fin tubes, and vacuum condenser design are also addressed. There are, in all, eleven case studies in this chapter to highlight various issues in condenser design.

Chapter 8 is on "Thermal design of reboilers," and begins with an account of pool boiling and the parameters which affect the same. After a brief discussion of flow boiling, the reader is then taken through an analytical description of the various types of distillation column reboilers which includes the principal features, advantages, and disadvantages of each. Among all reboilers, the design of vertical thermosyphon reboilers is the most elaborate and complex and flow regime, liquid circulation, tube size, elevation, and piping play a more profound role here than in other reboilers. Special considerations such as very wide boiling range, operation near critical pressure, film boiling and boiling at very low ΔT are all discussed in a lucid manner. The chapter closes after offering a guide on the selection of reboilers and a discussion of the start-up of reboilers. There are six case studies in this chapter on reboilers.

In Chapter 9, "Physical properties and heat release profiles," insight is offered on the various vapor and liquid physical properties which are essential for thermal design.These are necessarily to be furnished by the process licensor. Some unusual situations regarding variation of physical properties with temperature are reported, one example being hydrocarbon-hydrogen mixtures. The reader is given guidance on how to feed heat release profiles, a matter that is not as simple as it may appear.

The subject of overdesign of heat exchangers is perceived to be important enough to deserve an entire chapter, hence Chapter 10. It describes why overdesign is provided and discusses the modalities of overdesign for single-phase services, condensers, and reboilers. Guidelines are furnished regarding the optimum overdesign value for various situations. The effect of overdesign is brought out by case studies for two different situations, a high temperature approach case and a low temperature approach case.

Chapter 11, "Fouling: its causes and mitigation," is a chapter of considerable practical significance to the thermal designer, as fouling is often a severe problem. After reviewing the various categories of fouling and the parameters which affect it, suggestions are offered on how to specify fouling resistance. Comprehensive guidelines are then recommended in order to minimize fouling. Although fouling is an extremely complex phenomenon, it is still possible to minimize it by adopting these design practices. These range from the use of specific non-tubular heat exchangers in certain situations to various steps and measures the design engineer can adopt for STHEs, whether the fouling fluid is on the tubeside or on the shellside. One case study demonstrates how the shellisde velocity of a dirty stream can be increased and another case study shows the profound influence of fouling layer thickness on pressure drop.

Chapter 12 is on flow-induced vibration analysis. This is an extremely important subject as heat exchangers must be designed so that they are safe against failure of tubes due to flow-induced vibration. The mechanics of flow-induced vibration and the modes of tube failure are described. Guidelines are described for predicting flow-induced vibration. Four case studies are presented on how to produce designs that are safe against flow-induced vibration. The vital link between allowable pressure drop and flow-induced vibration is brought out clearly. Finally, there is a brief exposition of the mechanics of acoustic vibration with ways and means of preventing it.

Enhanced heat transfer is not a new subject, but it has become popular only of late. Chapter 13 dwells on enhanced heat transfer, the various techniques that are applied to achieve it, and its benefits as compared to conventional shell-and-tube heat exchangers.

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CHAPTER 2

Classification of Shell-and-Tube Heat Exchangers

2.1 Components of Shell-and-Tube Heat Exchangers

In order to be able to produce optimum designs, it is essential for the thermal designer to have a good working knowledge of the mechanical features of shell-and-tube heat exchangers (STHEs) and more importantly, how they influence thermal design.

The principal components of an STHE are:

a) shell
b) shell cover
c) tubes
d) channel
e) channel cover
f) tubesheet
g) baffles
h) floating-head cover
i) nozzles

Other components include tie-rods and spacers, pass partition plates, impingement plate, longitudinal baffle, sealing strips, sliding strips, supports, and foundation.

Tube bundle

The tube bundle is the heart of the shell-and-tube unit and comprises tubes, tubesheet(s), baffles, floating-head cover, split ring, tie-rods, spacers, impingement baffle, longitudinal baffle, and sealing/sliding strips.

The Standards of the Tubular Exchanger Manufacturers Association (TEMA) [1] should be referred to for the following description of these various components.

Tubes

Tubes represent the most vital component as it is through the tube-wall that actual heat transfer takes place. One fluid flows inside the tubes while another flows across or along the outside of the tubes. Tubes may be either seamless or electric resistance welded, but for reasons of mechanical integrity and thereby reliability, the former is usually preferred.

Tubes are usually defined by outer diameter (OD) and wall thickness (or BWG). Since the outer diameter is fixed and the inside diameter varies according to the thickness, it is

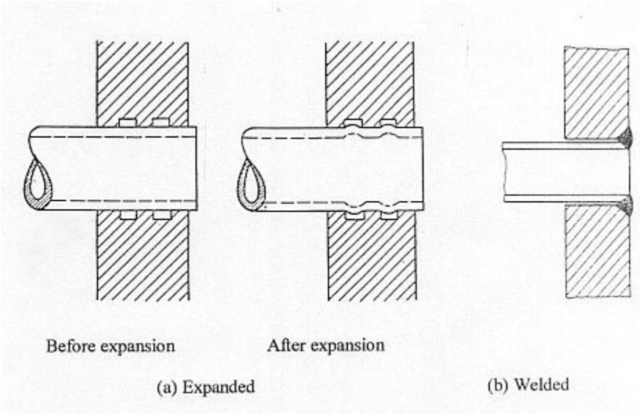


Fig. 2.1 Tube-to-tubesheet joint

more convenient to specify tubes by their outer diameter. Besides, outer diameter is more important than inner diameter as the holes in baffles and tubesheets have to be drilled based on the outer diameter of the tubes. Wall thickness can be either minimum wall (when there is no under-tolerance, but only over-tolerance) or average wall, when there is both under-tolerance and over-tolerance. The usual practice is to order tubes with minimum wall for carbon steel and low-alloy steel tubes, and with average wall for non-ferrous and high-alloy steel tubes.

Depending upon the nature of the working fluids, tubes are employed in various materials of construction, the principal being carbon steel, low- and high-alloy steels, special stainless steels, Admiralty brass and bronze, and alloys of copper and nickel in various proportions, including Monel, titanium, and even exotic materials, such as Hastelloys and tantalum. Tubes are usually bare, but in situations where the shellside heat transfer coefficient is highly controlling, low-fin tubes are sometimes used advantageously, provided the shellside fluid is not dirty.

Tubes are held at both ends (one end for U-tubes) by drilled plates called tubesheets. Whereas for fixed-tubesheet and U-tube heat exchangers, tubesheets are stationary, one of the two tubesheets in a floating-head heat exchanger is literally a floating tubesheet. Tubesheet thickness can vary from a mere 1 in. (25 mm) for low-pressure and low-shell diameter applications to over 12 in. (300 mm) in high-pressure and large-shell diameter applications.

Depending upon the severity of the situation, tubes are either expanded into grooves in the tubesheet or welded to them. An expanded tube-to-tubesheet joint usually has two grooves, as shown in Fig. 2.1a. The tubes are expanded by rotating-drill tube expanders so that tube metal actually flows into the grooves. Welded tube-to-tubesheet joints (Fig. 2.1b) afford higher integrity (albeit at a higher cost) and are usually employed for severe conditions, such as high pressure (say, in excess of 1140 psig or 80 kg/cm^2 g) or when handling toxic or inflammable fluids where leakage is not permitted. When the hot and cold streams cannot be allowed to mix, a special double-tubesheet construction is employed.

Baffles

Baffles serve to support the tubes as well as to impart a sufficiently high shellside velocity to yield a satisfactory heat transfer coefficient. Baffles are held securely in place by a combination of *tie-rods* and *spacers*. After a baffle has been guided along the tie-rods, a set of spacers is introduced over the tie-rods, after which the next baffle is inserted, and so on. Evidently, the length of the spacers is equal to the baffle spacing. Details of baffle configuration are discussed in detail in Section 3.4.4.

A small clearance between the tube outside diameter and the baffle hole diameter is essential to permit tubes to be inserted through baffles and assembly, as well as for tube replacement, if and when required. TEMA specifies this gap as 1/64 in. (0.4 mm) for a

Table 2.1: Table RCB-4.3 of TEMA Standards: Standard cross baffle and support plate clearances

Nominal Shell ID	Design ID of Shell minus Baffle OD
6–17 in. (152–432 mm)	1/8 in. (3 mm)
18–39 in. (457–991 mm)	3/16 in. (5 mm)
40–54 in. (1016–1372 mm)	1/4 in. (6 mm)
55–69 in. (1397–1753 mm)	5/16 in. (8 mm)
70–84 in. (1778–2134 mm)	3/8 in. (9.5 mm)
85–100 in. (2159–2540 mm)	7/16 in. (11.1 mm)

maximum unsupported tube length larger than 36 in. (900 mm) and 1/32in. (0.8 mm) for a maximum unsupported tube length smaller than 36in. (900 mm). A part of the shellside fluid leaks through this small gap: this is one of the shellside leakage streams and will be discussed in detail in Section 3.4.5. An excessive clearance provides excessive leakage and insufficient tube support with the possibility of vibration.

The outer diameter of the baffle has to be less than the inside diameter of the shell to permit insertion of the tube bundle into the shell and removal of the tube bundle from the shell. However, since the shellside leakage stream between the shell and the baffles is particularly detrimental to shellside thermal performance (see Section 3.4.5), this gap should be as small as possible. Table 2.1 shows this gap for various shell ID ranges, as per the TEMA standards.

Channel, channel cover, and pass-partition plates

The channel serves to introduce the tubeside working fluid into the exchanger as well as to direct it out of the exchanger. A channel may either be of a bonnet construction (TEMA head type B) where a dished end is welded to the channel barrel, or have a flanged channel cover (TEMA head type A). Pass-partition plates inside the channels serve to direct the tubeside fluid along the tubes as desired by the thermal engineer (i.e., they vary the number of tube passes). They fit tightly into grooves in the tubesheet and channel cover in order to eliminate the possibility of leakage of the tubeside fluid from one pass to the next—such leakage would evidently be highly detrimental to satisfactory performance of a heat exchanger. The actual sealing is effected by well-set gaskets that must be checked periodically and replaced whenever they are found wanting.

The arrangement of the pass-partition plates in multi-pass heat exchangers is somewhat arbitrary. However, all of them try to accomplish the following goals: maximize the number of tubes while employing a fairly even distribution of tubes in the various passes. Another consideration in some instances is to minimize the number of flow lanes in the flow direction when the same has a crucial bearing on the shellside stream analysis and, therefore, performance. For example, having two pass-partition lanes in the flow direction instead of three will result in a smaller pass-partition leakage stream flow fraction.

Some usual patterns of pass-partition arrangements for different numbers of tube passes are illustrated in Fig. 2.2.

Shell and shell cover

The shell serves to contain the shellside flowing stream and forms the outer casing of the tube bundle. It also serves to introduce the working fluids into the heat exchanger as well as to remove them from the heat exchanger. A shell cover is required in the case of split-ring pull-through floating-head heat exchangers.

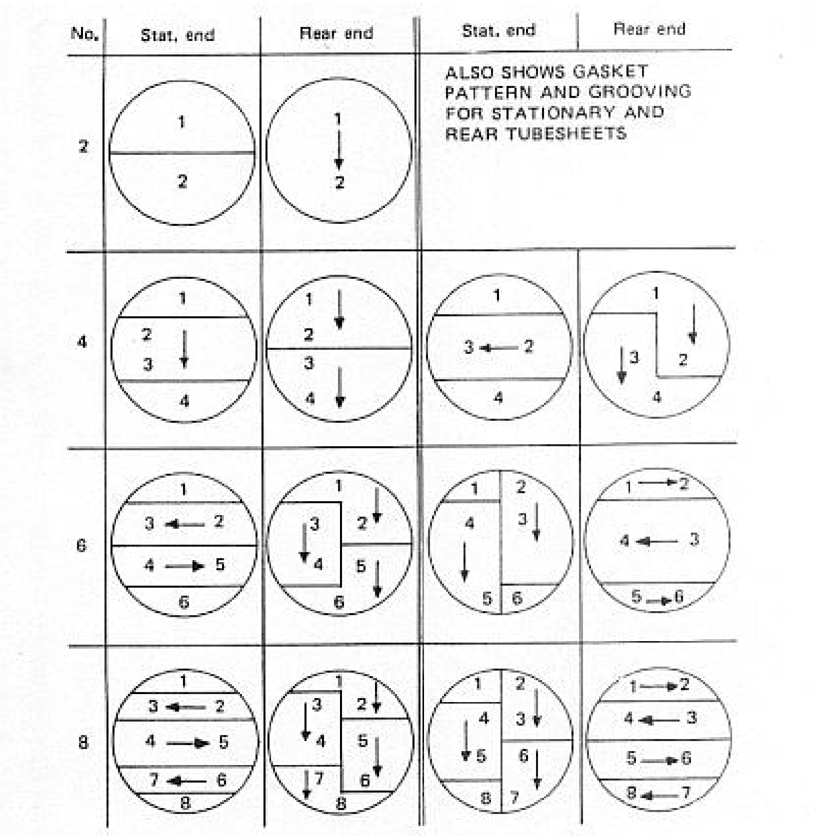


Fig. 2.2 Usual patterns of pass partition arrangements (Reprinted from the Heat Exchanger Design Handbook, 2002 with permission of Begell House, Inc.)

Impingement plate

The inlet nozzle is often provided with an impingement plate to protect the uppermost tubes located just below the shellside inlet nozzle against direct impingement by the shellside fluid. Such impingement can cause erosion, cavitation, and/or vibration. TEMA specifies an upper limit on ρv^2 of 1500 lb/ft sec^2 (2232 kg/m sec^2) for noncorrosive, non-abrasive single-phase fluids. For all other liquids, including a liquid at its boiling-point, the limit on ρv^2 is 500 lb/ft sec^2 (744 kg/m sec^2). For all saturated vapors and all two-phase mixtures, an impingement plate is always required as, in these services, it is possible to have liquid droplets traveling at vapor velocities, with very high values of ρv^2.

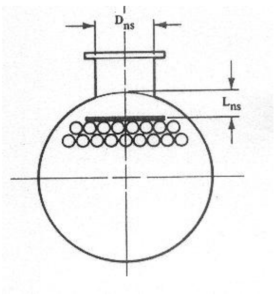


Fig. 2.3 Impingement plate (Reprinted from the Heat Exchanger Design Handbook, 2002 with permission of Begell House, Inc.)

An impingement plate must be located sufficiently below the shell ID so as to leave sufficient flow area between the shell and the plate for the flow to discharge without excessive velocity and, thereby, pressure loss. Consequently, a few rows of tubes usually have to be eliminated from the top of the tube field (see Fig. 2.3).

Sliding and sealing strips

A pair of sliding strips is provided at the bottom of floating-head tube bundles for their insertion and removal to and from

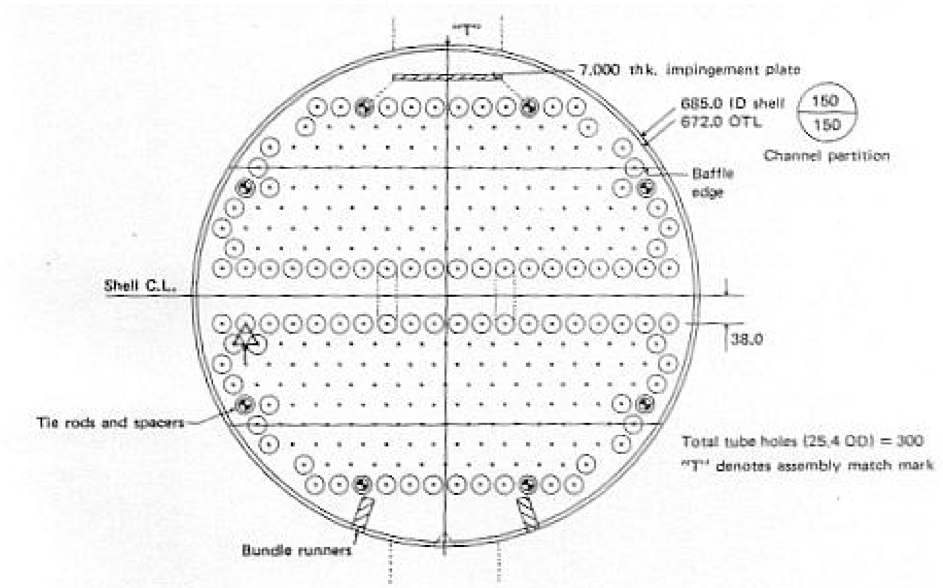


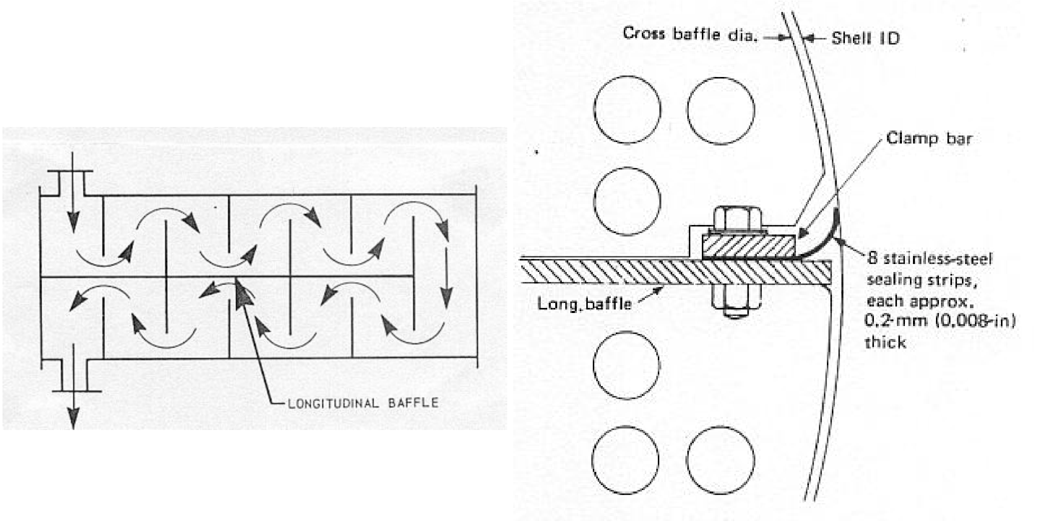
Fig. 2.4 Tube layout diagram (Reprinted from the Heat Exchanger Design Handbook, 2002 with permission of Begell House, Inc.)

the shell. A sufficient number of sealing strips is required to be inserted in the gap between the shell and the outermost tubes in floating-head tube bundles to minimize leakage of the shellside fluid around the tube bundle.

A typical tube layout drawing is shown in Fig. 2.4, showing many of the above components, viz., tubes, tie-rods, sealing strips, sliding strips, and impingement plate.

Longitudinal baffle

By its very name, a longitudinal baffle is placed transversely along the centerline of the shell and is employed to divide the shell into two or more compartments (see Figs. 2.5a



(a) Schematic **(b) Typical arrangement**

Fig. 2.5 Longitudinal baffle (Reprinted from the Heat Exchanger Design Handbook, 2002 with permission of Begell House, Inc.)

and 2.5b). For example, a single longitudinal baffle from one tubesheet to just short of the other tubesheet produces an F shell, that is, a shell with two shell passes. Longitudinal baffles may also be employed to produce G and H shells (see Fig. 2.6).

It will be apparent that in the case of removable tube bundles, the longitudinal baffle will be a part of the tube bundle and can therefore not be fixed to the shell. In order to prevent bypassing of the shellside fluid from the first pass to the second pass along the edges of the longitudinal baffle in an F shell, flexible strips are employed at both ends of the longitudinal baffle, all along the length of the shell (Fig. 2.5b). Also, the shellside pressure drop is usually limited to 0.35 kg/cm^2 in F shells in order to minimize the possibility of leakage across the longitudinal baffle.

However, in the case of fixed-tubesheet heat exchangers, since the tube bundle cannot be removed from the shell, the longitudinal baffle can be fixed to the shell by welding.

TEMA has developed a nomenclature for the specification of various construction types. An STHE is divided into three parts: the front head, the shell and the rear head. The nomenclature for the various construction possibilities are shown in Fig. 2.6.

2.2 Front and Rear Heads

Referring to the classification in TEMA (Fig. 2.6), there are five front head types: A, B, C, D, and N. There are eight rear head types: L, M, N, P, S, T, U, and W, which correspond in practice to only three general construction types, namely fixed-tubesheet, U-tube, and floating-head. Rear head L is identical to a front head A, and rear head M is identical to a front head B, while N is the same nomenclature. These three rear head types belong to fixed-tubesheet heat exchangers. U applies to U-tube heat exchangers while S, T, P, and W represent various types of floating-head construction. In the following section, the different types of heads will be discussed. The overall classification of fixed-tubesheet, U-tube, and floating-head heat exchangers will be discussed in Section 2.3. The various shell types will be discussed in Section 3.4.1.

A/M-type head

In this type, the channel barrel is flanged at both ends. The tubesheet is bolted to one flange and a flat channel cover to the other. Thus only the channel cover has to be removed for cleaning of the tubes by rodding or hydro-blasting; the channel and piping are not disturbed. However, for any inspection or repair of a tube-to-tubesheet joint, the entire channel will usually be required to be removed, especially for peripheral tubes. Removal of the entire channel is also required for removal of the tube bundle.

Despite its higher cost due to the presence of two flanged joints, this type of channel is very commonly used, especially in petroleum refineries where dirty fluids are handled, necessitating frequent bundle removal.

B/M-type head

In this construction, the channel barrel is flanged at one end only, the other end being welded to a semi-elliptical bonnet or dished end. This type is lighter and cheaper than the A type, especially at high pressures, as the thickness of the bonnet is considerably less than that of a flat cover plate. Here the entire bonnet has to be removed for cleaning even the inside of tubes, which means that the channel piping connections have to be dismantled. For removal of the bundle for cleaning the outside of tubes, the entire channel has to be removed anyway, as indeed has to be the A-type channel. Therefore, this channel type is recommended for services where the tubeside fluid is clean. It will be seen in Section

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