## 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 $\Delta T$ 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.

## References


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