HEAT EXCHANGERS:
A Practical Approach to Mechanical Construction, Design, and Calculations

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HEAT EXCHANGERS

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FOREWORD

I have been aware of and quite impressed by the work of Dr. M. Podhorsky and his co-author, H. Krips, for a number of years, in particular for their exceptional contribution to the development of the hydraulic expansion process for the manufacturing of tube-to-tubesheet joints. I was therefore delighted and honored to have been invited by Dr. Podhorsky to write a foreword for the English translation of his book on Heat Exchangers.

This book offers an interesting overview of procedures for designing heat exchanger pressure vessels; although the approach is based mainly on the German Code standards, it regularly refers to and provides comparisons with the ASME Code.

The authors draw extensively from their wide industrial experience combined with a thorough understanding of the theory underlying the code procedures. Their approach is systematic and easy to follow and they use numerous illustrations to make their point. They cover the field with just necessary details and leave it to the reader to complement his or her information from the available design codes.

Chapter 1 provides an excellent description of the many types of heat exchangers found in the field, their applications, and the many practical problems that could be encountered (in particular those related to corrosion and vibration damage). It is an excellent "entrée en matière" for the experienced and inexperienced designers alike.

Detailed design procedures are given in Chapters 2 and 3. While Chapter 2 provides details on the discontinuity analysis approach for computing the stresses in the various pressure vessel components, Chapter 3 looks particularly at the design of tubesheets.

I was particularly interested in the authors' handling of the gasketed bolted flanged joint in Chapter 4. They are among the few who have tackled the problem in a complete manner, i.e., as a complex mechanical assembly whose purpose is to operate satisfactorily, not only in terms of pressure integrity but also in terms of leak tightness. It is, of course, beyond the scope of this book to cover in detail the extensive research work—more specifically that sponsored by the Pressure Vessel Research Council—that has recently been carried out of gasket evaluation alone. But it is interesting that their approach systematically takes into account the gasket as a full fledged mechanical element in the analysis. The fact that the ASME code is considering the introduction of new gasket factors and a new design procedure for gasketed flanged joints is an indication that the authors were pioneers in their approach.

Chapter 5 on Methods of Fastening Tubes to Tubesheets and Headers is, by itself, a justification to buy this book. It offers an excellent overview of the various methods available for securing a tight joint between the tube and the tubesheet. The authors cover all the methods in detail including, of course, the hydraulic expansion process which they pioneered. Having personally carried out research on the residual stresses generated in heat exchanger tubes by the various expansion processes discussed in the book, I can only but concur that the hydraulic process is the one that generates the least unwanted residual stresses while ensuring a systematic and uniform tube-tubesheet joint.

INTRODUCTION

The reliable operation of the individual elements of a system has taken on extremely great significance as a result of the rapid increase in both the capacity and complexity of the systems which involve vast amounts of capital expenditure. The heat exchanger is one of the components occurring most frequently in a system.

The book focuses on tube heat exchangers which contribute significantly to economic efficiency in the power station circuit. It covers sophisticated heat exchangers subjected to high operating loads from whose design and construction valuable information has been gathered. This information has been condensed here for the technically interested reader.

The first chapter deals with heat exchangers for power stations. It gives basic recommendations on the admissible loads, corrosion and erosion stresses, and on the main component assemblies. The basic process engineering rules and recommendations are also presented. Such information could therefore be valuable not only to young engineers but also to those with practical experience who might find ideas to improve a system through reading it.

The second chapter goes into the details of the fundamental elements which make up a heat exchanger or a pressure vessel. The deformation equations are given and explained so that the basic physical data of a stress analysis can be derived for a heat exchanger or pressure vessel subjected to internal pressure and thermal stress. The combination of the individual force method elements via the compatibility condition in the individual sections is specified to allow simple programming. The purpose of this chapter is to provide more basic information about the elementary components of the pressure vessel and to present the mathematical formulation in a clear manner.

The third chapter concentrates on some specific details relating to the design of a tubesheet. The tubesheet is a typical component of a heat exchanger which requires particular attention due to the geometrical inhomogenity in the section to be tubed.

The penultimate fourth chapter discusses the dimensioning of the various flange constructions in detail. Even today, a correctly designed flange joint is still unfortunately not a matter of course. The reason for this is the complexity of the joint which is subjected to the interaction of all the elements and also the fact that the design codes are in some cases simplified in a technically inappropriate manner. The gasket represents the additional unknown factor. It can have different sealing properties despite identical geometrical dimensions. The method of production and the material processing during production play a decisive role. Although the reliability of the entire plant during operation and during the start-up and shutdown procedures depends on the tightness of the heat exchanger connection, the problems relating to this connection are only seldom treated systematically and critically. This analysis covers both the flange design and the flange installation because these elements are directly interlinked. A correctly designed flange will leak if not correctly installed and vice versa. Attention is drawn to the fact that the deformation behavior of flanged covers differs fundamentally from the behavior described in the design codes and must therefore be treated separately.

The fifth and final chapter of the book also deals with a problem given little attention in the relevant literature and that is the problem of reliably fastening the tubes in the tubesheets. The authors have carried out very extensive work in this field. The invention of the process to hydraulically expand tubes into tubesheets and its introduction throughout the world are proof of this. The quality of the tube/tubesheet joint frequently determines the operating reliability of expensive and sophisticated process systems. Therefore it should be given due attention. All currently used methods of fastening tubes in tubesheets are set out and the advantages and disadvantages of each discussed.

The book was purposely restricted to those topics which can offer the reader new facts, the latest information gained through practical experience, or new solutions.

1
HEAT EXCHANGERS FOR POWER STATIONS

Power consumption and economic efficiency have led to a continual increase in the output of power generating units. Mass flow increased to the same degree as the output and consequently it became necessary to adapt the size of the components accordingly. This increase in size, however, is not just a question of adapting the geometry, because when certain limits are exceeded it becomes necessary to set new criteria. The extent to which such criteria can be incorporated in the design of heat exchangers by increasing their size is, however, limited. It then becomes necessary to split the component into two or several parallel units.

There is one heat transfer component element whose dimensions cannot be adapted by increasing its size: the heat exchanger tube, the outer diameter of which seldom exceeds 16 to 25 mm in heater construction. This restriction with respect to the tube diameter narrowed the scope for modifications in length in order to avoid high pressure drop or eroding velocity. Therefore, to achieve a higher output it is the number of tubes and not their size that has to be changed.

The number of tubes making up a heat exchanger or several parallel units of a thermal stage indirectly indicates the output of the plant. This number increases virtually in proportion to the increase in the size of the plant. However, the possibility of damage to the tubes and to their joints also increases in the same proportion. In the 1950's the average output of a power plant was 50 MW whereas currently the mass flow rate in a single heat exchanger corresponds to 700 MW and the number of tubes is 14 times as high. Therefore, assuming that the current components have the same operating life as the ones used previously, the damage safety margin for the tubing must be 14 times higher. This safety margin needs to be even higher because the increased costs incurred through a loss in running time of large industrial plants must be taken into account. It is therefore obvious that the measures to increase operating time should concentrate mainly on testing and protection of heat exchanger tubes. It goes without saying that the other pressure and structural parts have to meet specific safety requirements.

Proper design and material selection and good engineering produce high quality components only if accompanied by a stringent quality control system and if the manufacturing of the parts is monitored by appropriate testing.

Quality control and testing ensure economic efficiency. They help to guarantee running time and to reduce the manufacturing costs. Quality control personnel must, however, also be involved right from the design phase so that the testing required during manufacturing can be restricted to a minimum.

1.1 HEAT EXCHANGER TUBES

As a rule, tubes are made of ST 35.8 I, ST 35.8 III or 15 Mo 3*, depending on pressure and temperature. The tubes in low pressure heaters are joined to the tubesheet by rolling or by

*For material equivalence please see List of Materials at the end of the book.

hydraulic expansion using the **HY**draulic **T**ube **EX**pansion (HYTEX) process. The tubes in high pressure (HP) heaters are welded to the headers or the tubesheets and also hydraulically pressed or rolled in the tubesheets.

Conventional tube materials have proved to be suitable provided that the heat exchanger design takes into account the effects of pressure, temperature and medium involved. When designing a component, precautions must be taken to prevent: erosion, corrosion-erosion, droplet impingement, corrosion and vibration.

1.1.1 Erosion and Corrosion-Erosion

Erosion and corrosion-erosion are the main cause of damage to exchangers. These can be avoided by taking appropriate precautions.

On the water side (inside of tubes) the flow rate is kept within specific limits to avoid erosive vortices in the inlet flow (Fig. 1.1). The flow rate in the C-steel tubes is generally 1.8 m/s and lower; this rate may only be increased to 2 m/s if the tube openings have been appropriately designed. The maximum flow- rate for stainless steel tubes is 2.5 m/s and in this case plant-specific criteria such as pressure drop are the decisive factors. Lower flow rates can also cause corrosion-erosion in C-steel tubes if the pH value is below 9. Particular attention must be paid to flow conditions with these modes of operation.

It is not the rate of the mass flow alone which causes damage; the geometry of the water box and the header also plays a role. When determining the number of tubes required for a rate of 1.8 to 2 m/s, it is assumed that the flow rate through each of the tubes is identical. Apart from some tolerable variations which occur due to the difference in length of the internal and external U-tube, this is normally the case. This uniformity is frequently disrupted by water boxes which are too small, because the water inlet flow does not have an adequate distance to develop. Inlet nozzles arranged laterally and immediately upstream of the tubesheet pose a danger for the tube inlets as they entrain vortices and disrupt distribution. It is particularly important to take this into account for HP heaters operating in the temperature range above 150°C. It may be necessary to provide a flow rectifier here in addition to rounding off the tube inlet. (Fig. 1.2).

The streamlined openings of the rectifier are aligned with the tube openings. Their diameter corresponds to the inside tube diameter. The ratio of sheet thickness to opening

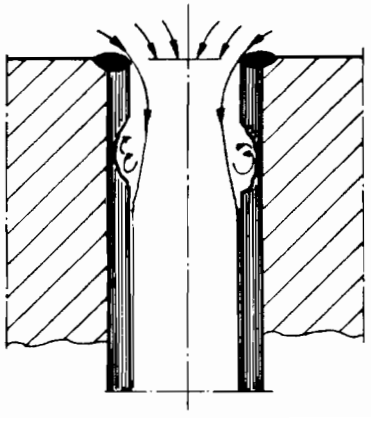

Fig. 1.1 Erosion in the tube inlet.

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