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PRATICAL HEAT TRANSFER

by

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ABOUT THE AUTHOR

Peter Hills was educated at Manchester Grammar School and Imperial College, London, where he was awarded a BSc(Eng) in Chemical Engineering and a PhD for a study of gas-liquid flow in tube bends.

He joined Imperial Chemical Industries (ICI) in 1968, and after periods spent in process development, plant investigations and process design, was appointed in 1982 the senior heat transfer and fluid flow consultant for the ICI Group, a position which he held until retirement in 2000. He represented ICI at HTRI and HTFS, and was a member of several HTFS technical advisory bodies. Since retiring from ICI he has continued to practice as an independent consultant.

He has published several papers in the fields of heat transfer and fluid flow, and has contributed to the Heat Exchanger Design Handbook. He is a member of the UK National Committee for Heat Transfer, a Fellow of the Institution of Chemical Engineers and a Chartered Engineer in the UK.

FOREWORD

Technical training in the design and operation of heat transfer systems can nowadays proceed seamlessly from simplistic models taught at the undergraduate (and even graduate) level, to learning, once the graduate proceeds to an industrial post, how to implement sophisticated commercial codes for rating and design of heat exchangers. More and more, the results from such code implementations are accepted blindly, with often-undesirable consequences. This is not, of course, a criticism of the codes themselves but, rather, of how they are used.

It is thus very timely to present a book in the Series on Thermal and Fluid Physics and Engineering which directly and effectively addresses this problem. The Author, Peter Hills, has had more than 25 years of experience in working on a very wide variety of heat transfer applications. Furthermore, he has used extensively the main commercial codes and is therefore able to discuss authoritatively the pitfalls that the engineer may encounter in their blind acceptance. There is no substitute for experience and the principal aim of this monograph is to try to present the author's own wide experience so as to avoid at least some of the difficulties encountered in real systems.

I believe that this book should be on the desks of all those involved in heat transfer system design!

G. F. Hewitt
Series Editor

PREFACE

Jerry Taborek, the founding Technical Director of Heat Transfer Research Inc. (HTRI), used to say 'Computer programs do not design heat exchangers - engineers do'. Although I agree totally with the sentiment behind Jerry's statement, it has been my experience that on too many occasions, engineers have left the design of equipment almost completely to the computer programs, and forgotten that they, the engineers, have ultimate responsibility.

It is true that since Jerry made his statement, the sophistication of heat exchanger design software has increased dramatically, and modern codes attempt to be 'expert systems' which can advise the designer. None the less, the best designs are produced by those who understand what they are doing, and the limitations of the programs they are using, rather than by those who use the programs as magic ‘black boxes’. This book is designed to help the engineer in this task.

The book is concerned with the Thermal design process, not Mechanical design. Although comments are made throughout the book on matters of a mechanical nature, and Chapter 7 contains a section on how mechanical constraints influence the thermal design process, the information given is for guidance only. The final design must be checked for compliance with the appropriate mechanical design code by a competent mechanical engineer.

SOURCES FOR THE BOOK

In the early 1990's, The Process Engineering Committee of Imperial Chemical Industries PLC (ICI) decided that it would be of benefit to the company if much of the accumulated practical knowledge of the many process specialists scattered around the Group were codified into a form which would be readily available to the general practising process engineer. Accordingly, a series of 'Process Engineering Guides' was written. As the senior internal consultant in heat transfer, it fell to my lot to write most of the Guides in the Heat Transfer series. This book is based on those Guides, although it has been supplemented with other material, and the arrangement of the information restructured.

It was never the intention that the ICI Guides would replace standard textbooks. The emphasis was more on practical applications than on the theory. This approach has been carried over into this book, and is reflected in its title. Readers will not find much detailed heat transfer theory here. Indeed, it is in general assumed that they already have a reasonable understanding of the theory. If not, they are referred to one of the many excellent text books on heat transfer, or back to their university notes! In any case, the better computer codes for exchanger rating incorporate the best methods. The aim of the book is rather to give guidance on those aspects of heat transfer which are often not covered in university heat transfer courses, but which practical experience suggests are important.

ACKNOWLEDGEMENTS

A book of this nature, based as it is on accumulated practical experience, can never claim to be the work of one man. Those to whom I am indebted are too numerous for me to name them all.

My general education in practical heat transfer owes much to technical discussions, both formal and informal, held with both staff and sponsors of the two major heat transfer research organisations with which ICI has been associated over the years, HTRI and HTFS, although I believe that I have not included in this book any proprietary information obtained in this manner without permission.

Among my colleagues within ICI, I wish particularly to acknowledge the help and support over the years of my two predecessors as principal internal heat transfer consultant: Bob Smith and Geoffrey Walter; the members of the ICI Heat Transfer Panel who provided both material and constructive criticism during the writing of the ICI Guides: David Bate, Ian Buckley, Reg Crane, Peter Farnell, Richard Fawcett, Peter Gowland, Neil McNaughton and Neil Turner; and the chairman of the ICI Water Treatment Panel, Rob Terrell.

The ICI Guide on Air Cooled Heat Exchangers, on which Chapter 8 of this book is based, made extensive use of a report written for ICI by C.M.B. Russell, formerly of Lummus Heat Transfer.

I am grateful to those companies and organisations which have supplied me with, or given permission to use, the various illustrations in this book. I trust that they find any comments I have made on their products to be accurate and fair.

Finally, as stated above, this book is based on internal ICI reports, and I am grateful to ICI for permission to publish.

DISCLAIMER

Although this book makes extensive use of the internal ICI guides mentioned above, the views expressed in the book are my personal opinions, given in good faith, and are not necessarily those of the company. Imperial Chemical Industries PLC do not accept any responsibility for the contents of the book nor for the consequences of any actions based on the advice given in it.

Within this book I mention by name several companies and research organisations. In so doing, I hope that I am providing accurate factual information, but no specific endorsement of any company or product is intended. Equally, failure to mention other companies producing material similar in nature to those mentioned is not intended in any way as a criticism of such companies. New companies appear from time to time, and existing ones either cease trading or are subject to take-over. Equipment and software are continuously being developed, and specifications change, and even were I to mention all suppliers and equipment, the list would rapidly become out of date.

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CHAPTER 1

HEAT EXCHANGER SELECTION

1.1 INTRODUCTION

Although by far the majority of heat exchangers used on chemical and petrochemical plant are shell and tube units, they are not necessarily the best choice, and there are many other types available. The engineer may have little knowledge of the attributes of these other types, so is not able to make an informed selection. This chapter aims to assist in this task. After covering some of the drawbacks of the shell-and-tube design, some of the obstacles which have to be overcome in order to introduce an alternative design are discussed. The factors which influence the choice of heat exchanger are described and the various types available are introduced, giving some of their advantages and disadvantages.

This chapter does not give hard and fast rules which will automatically lead to the selection of the 'best' exchanger for a given duty; indeed, often there is no one correct solution. Rather it seeks to give the engineer information to assist in making a rational choice.

Some of the alternative designs are proprietary in nature, in some cases being produced by a single manufacturer. In referring to these types, no specific endorsement of the product or company is implied. Equally, failure to mention a particular type or manufacturer should not be taken as implying a criticism. The area of proprietary heat exchanger design is in a continuous state of change, with new designs appearing or being withdrawn, and companies being subject to take-over. The information is given in good faith, but represents my personal views. The final decision on what unit to purchase lies with the specifying engineer, and it is up to him to find all the relevant facts before making a decision.

1.2 BACKGROUND

Major increases in profits for a chemical or petrochemical manufacturer are more likely to come through the development of new products or processes than from the selection of better heat exchangers. Because of this, the order of emphasis in selection of individual exchangers is:-

- Safety and reliability.
- Performance.
- Cost.

Attempts have been made in the past to develop selection methods for heat exchangers, either in the form of flowcharts or scoring techniques. These approaches often implicitly assume that there is a single 'right' solution for each problem. This is rarely the case. An initial screening can be done to reject designs which are unsuitable for reasons of materials, operating conditions or safety, for example, but the engineer will often then be left with a range of designs to consider. The final decision will be based on engineering judgement.

A survey by Wood (1995) indicated that over 85% of new exchangers supplied to the refining, chemical, petrochemical and power industries in leading European countries were of the shell and tube type. Although not necessarily the ‘best’ design, shell and tube exchangers can give satisfactory performance on most duties and their design, operation and maintenance are well understood. Because of this they are likely to be the standard against which any alternative will be judged. Before going on to consider alternative designs, it is worth while noting the shortcomings of the shell and tube design, and also considering some of the 'political' rather than technical considerations which are involved in the selection process.

1.2.1 *Limitations to the shell and tube design*

For general information on shell and tube exchangers see chapter 7.

The design of a heat exchanger is strongly influenced by mechanical as well as process considerations. The tubes of the shell and tube exchanger are well suited to withstand high pressures. However, the hydraulic diameter is relatively high, and the surface to volume ratio is low. There can be severe mechanical problems in fastening the tubes into the tubesheet if there is significant differential expansion. The large hydraulic diameter does make mechanical cleaning of the tube side easy, but, because the shear rates are low compared with some of the compact designs, the tendency to foul may be greater in the first place. The large hydraulic diameter also results in a long flow path for a given duty, which may require the use of multi-pass designs, with resulting loss of temperature driving force.

The situation on the shell side is much worse. In the conventional TEMA-type exchanger (see chapter 7 for a description of the TEMA nomenclature), baffles are provided on the shell side. These baffles serve two functions: they provide support for the tubes to reduce vibration, and they direct the shell-side fluid to flow across the tubes, increasing the velocity and hence the heat transfer. However, the resulting flow pattern gives a relatively high pressure drop per unit of heat transfer, because pressure drop is wasted in the repeated flow reversals after each cross pass. Moreover, clearances on the shell side, necessary for constructional reasons, can result in severe by-passing, with not all the shell-side fluid contacting the heat transfer surface.

Lack of perfect radial mixing, the presence of some longitudinal mixing, the fact that the by-pass streams do not play a major part in the heat transfer and the need for multi-pass operation on the tube-side, result in the effective mean temperature difference and the exchanger thermal effectiveness being less than the ideal values. Because of this, shell and tube exchangers are generally unsuitable when a high thermal effectiveness, say greater than 90%, is required.[1] These problems are less with some of the designs of compact exchanger.

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[1]The thermal effectiveness of a heat exchanger is defined as the ratio of the actual heat transfer rate to the maximum possible rate which could be achieved in an exchanger of infinite length operating in ideal counter-current flow.

Rotary regenerators, on the other hand, generally use fabricated metal matrices constructed of very thin strips of metal, giving a large surface to volume ratio. The metal has to be selected to withstand the possible corrosive conditions.

Increasing interest is being shown in phase-change materials for thermal storage, because they have small temperature swings, the major part of the stored energy being in latent heat. These can be of particular interest for operations where there is a delay between heating and cooling requirements.

1.4.15.3 Applications. Fixed bed regenerators are used extensively in the metallurgical and glass-making industries, where very high temperature gases may be involved. Rotary regenerators are common as air pre-heaters in the power generating industry. They are also used in gas turbine plants for vehicles, in cryogenic refrigeration applications and in food dehydration.

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