Foreword

It is a real surprise and pleasure to read this "brainy" book about convective heat transfer. It is a surprise because there are several books already on this subject, and because the book title is deceiving: here "solved problems" means the structure of the field and the method of teaching the discipline, not a random collection of homework problems. It is a pleasure because it is no-nonsense and clear, with the ideas placed naked on the table, as in elementary geometry.

The field of convection has evolved as a sequence of solved problems. The first were the most fundamental and the simplest, and they bear the names of Prandtl, Nusselt, Reynolds and their contemporaries. As the field grew, the problems became more applied (i.e. good for this, but not for that), more complicated, and much more numerous and forgettable. Hidden in this stream, there are still a few fundamental problems that emerge, yet they are obscured by the large volume.

It is here that this book makes its greatest contribution: the principles and the most fundamental problems come first. They are identified, stated and solved.

The book teaches not only structure but also technique. The structure of the field is drawn with very sharp lines: external versus internal convection, forced versus natural convection, rotation, combined convection and conduction, etc. The best technique is to start with the simplest problem solving method (scale analysis) and to teach progressively more laborious and exact methods (integral method, self-similarity, asymptotic behavior).

Scale analysis is offered the front seat in the discussion with the student. This is a powerful feature of the book because it teaches the student how to determine (usually on the back of an envelope) the proper orders of magnitude of all the physical features (temperature, fluid velocity, boundary layer thickness, heat flux) and the correct dimensionless groups, which are the fewest such numbers. With them, the book teaches how to correlate in the most compact form the results obtained analytically, numerically and experimentally.

In summary, this book is a real gem (it even looks good!). I recommend it to everybody who wants to learn convection. Although the authors wrote it for courses at the MS level, I recommend it to all levels, including my colleagues who teach convection.

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Preface

Heat transfer is associated with flows in a wide spectrum of industrial and geophysical domains. These flows play an important role in the problems of energy and environment which represent major challenges for our society in the 21st century. Many examples may be found in energy-producing plants (nuclear power plants, thermal power stations, solar energy, etc.), in energy distribution systems (heat networks in towns, environmental buildings, etc.) and in environmental problems, such as waste-heat release into rivers or into the atmosphere. Additionally, many industrial processes use fluids for heating or cooling components of the system (heat exchangers, electric components cooling, for example). In sum, there are a wide variety of situations where fluid mechanics is associated with heat transfer in the physical phenomena or in the processes involved in industrial or environmental problems. It is also worth noting that the devices implied in the field of heat transfer have dimensions bounded by several meters, as in heat exchangers up to tenths of microns in micro heat-transfer applications which currently offer very promising perspectives.

Controlling fluid flows with heat transfer is essential for designing and optimizing efficient systems and requires a good understanding of the phenomena and their modeling. The purpose of this book is to introduce the problems of convective heat transfer to readers who are not familiar with this topic. A good knowledge of fluid mechanics is clearly essential for the study of convective heat transfer. In fact, determining the flow field is most often the first step before solving the associated heat transfer problem. From this perspective, we first recommend consulting some fluid mechanics textbooks in order to get a deeper insight into this subject. Therefore, we recommend the following references (the list of which is not exhaustive):

– general knowledge of fluid mechanics [GUY 91], [WHI 91] [CHA 00] and, in particular, of boundary layer flows [SCH 79];

– turbulent flows [TEN 72], [REY 74], [HIN 75].

The knowledge of conductive heat transfer is, obviously, the second necessary ingredient for studying convective transfer. Concerning this topic, we refer the reader to the following textbooks: [ECK 72], [TAI 95], [INC 96], [BIA 04].

The intention of this book is to briefly introduce the general principles of theory at the beginning of each chapter and then to propose a series of exercises or problems relating to the topics of the chapter. The summary presented at the beginning of each chapter will usefully be supplemented by reading textbooks on convective heat transfer, such as: [BUR 83], [CEB 88], [BEJ 95].

Each problem includes a presentation of the studied case and suggests an approach to solving it. We also present a solution to the problem. Some exercises in this book are purely applications of classical correlations to simple problems. Some other cases require further thought and consist of modeling a physical situation, simplifying the original problem and reaching a solution. Guidelines are given in order to help the reader to solve the presented problem. It is worth noting that, in most cases, there is no unique solution to a given problem. In fact, a solution results from a series of simple assumptions, which enable rather simple calculations. The object of the book is to facilitate studying flows with heat transfer and to propose some methods to calculate them. It is obvious that numerical modeling and the use of commercial software now enable the treatment of problems much more complex than those presented here. Nevertheless, it seems to us that solving simple problems is vital in order to acquire a solid background in the domain. This is a necessary step in order to consistently design systems or to correctly interpret results of the physical or numerical experiments from a critical point of view.

Industrial projects and geophysical situations involve relatively complex phenomena and raise problems with a degree of difficulty depending on the specificity of the case under consideration. We restrict the study of the convective heat transfer phenomena in this book to the following set of assumptions:

– single-phase flows with one constituent;

– Newtonian fluid;

– incompressible flows;

– negligible radiation;

– constant fluid physical properties;

– negligible dissipation.

However, in Chapter 1 only the last two points will be discussed.

The first chapter presents the fundamental equations that apply with the above list of assumptions, to convective heat transfer and reviews the main dimensionless numbers in this topic.

Most flows present in industrial applications or in the environment are turbulent so that a large section at the end of the book is devoted to turbulent transfer. The study of laminar flows with heat transfer is, however, a necessary first step to understanding the physical mechanisms governing turbulent transfer. Moreover, several applications are concerned with laminar flows. This is the reason why we present convective heat transfer in fully developed laminar flows in Chapter 2.

A good knowledge of boundary layers is extremely important to understanding convective heat transfer, which most usually concerns flows in the vicinity of heated or cooled walls. Consequently, Chapter 3 is devoted to these flows and several problems are devoted to related issues. This chapter is complemented by the next one, which is concerned with heat transfer in flows around obstacles.

Chapters 5 and 6 deal with natural convection in external and internal flows. The coupling between the flow field and heat transfer makes the corresponding problems difficult and we present some important examples to clarify the key points relative to this problem.

Turbulent transfer is presented in Chapters 7 to 9, for flows in channels and ducts, in boundary layers and finally in free shear flows.

Scale analysis [BEJ 95] is widely used in this textbook. It is quite an efficient tool to use to get insight into the role played by the group of parameters of a given physical situation. Scale analysis leads to the relevant dimensionless numbers and enables a quick determination of the expected trends. The information given by this analysis may be used as a guideline for simplifying the equations when a theoretical model is implemented and for interpreting the results of numerical simulations or physical experiments. This approach has the notable advantage of enabling substantial economy in the number of studied cases since it is sufficient to vary few dimensionless numbers instead of all the parameters to specify their influence on, for example, a heat transfer law.

Other classical methods of solving are presented in the review of the theoretical principles and are used in the presented problems (autosimilarity solutions, integral method).

This book is addressed to MSc students in universities or engineering schools. We hope that it will also be useful to engineers and developers confronted with convective heat transfer problems.