

Preface

The use of lasers in materials processing has become widespread in recent years, so that an understanding of the nature of heat and mass transfer in this branch of modern technology is of increasing importance. The aim of the authors of this book is to concentrate on the physical processes; these can be developed from a mathematical point of view, or from direct experimentally derived observation. The two approaches are complementary; each can provide insights and the synthesis of the two can lead to a very powerful understanding of the processes involved. Mathematical modelling of physical processes has had an important role to play in the development of technology over the centuries and particularly so in the last 150 years or so. It can be argued that it is more important today than ever before since the availability of high-speed computers allows accurate numerical simulation of industrial processes at a fraction of the cost of the corresponding experiments. This is one aspect of mathematical modelling, high profile and much valued, but it is not the only one.

In the past mathematical modelling had to rely on qualitative investigation, very special analytical solutions, or inaccurate and time-consuming calculations performed with little in the way of tabulated or mechanical assistance. Log tables and slide rules are still remembered by people working today, though there are surely few who regret their disappearance.

The value and distinctive function of methods based on the analytical approach is now becoming much clearer, now that they are no longer expected to produce detailed imitations of what happens in real experiments of industrial processes, a function now fulfilled mostly by numerical methods, considered below. The emphasis today is on their ability to confirm and extend our understanding of the basic physical mechanisms involved in the processes of interest. These are essential for any intelligent use of numerical simulation.

The argument about the value of teaching people how to do arithmetic themselves without the aid of a calculator seems to be passing into history, but it is an important one and provides a simple analogy. If someone does not have a feeling for numbers and the way arithmetic works, they will all too easily fail to spot an error produced by a machine. Computers are not infallible—and neither are those

who build or program them. Computers are now taking on less mundane mathematical tasks and the same controversies are appearing in connection with algebraic manipulation. Equally, and with even greater penalties in terms of cost in the event of errors, the same considerations apply to numerical simulation of major industrial processes. Awareness of the analytical solutions can be invaluable in distinguishing the right from the wrong, i.e. for the practitioner to understand the basis of the work, and to have an idea of the kinds of outcomes that are plausible—and to recognise those which are not.

The phrase *mathematical modelling* is, however, ambiguous, perhaps more now than it has ever been. There is an enormous amount of work done today on simulation based on the use of very powerful computer programs, and it is quite correctly referred to as mathematical modelling. The programs are sometimes constructed in-house but are usually commercial packages. This is an entirely valid approach with specific (generally commercial) objectives. In general there are two uses. The dominant objective is initially numerical agreement with a particular experiment, leading subsequently to predictive commercial use. The second objective is the clarification of physical mechanisms, aimed at the generation of understanding of complex interconnected processes, rather than the exact reproduction of a particular experiment. It is sometimes overlooked that, with sufficient care, a numerical approach is equally valid in the investigation of physical fundamentals. Numerical simulation is not a central topic of this book, but because of its crucial importance to each of the two uses to which numerical modelling can be put, it is vital that the computational basis of the work should be completely sound. In addition, the level of process detail which can be considered by the numerical approach usually exceeds what is possible with the analytical approach by a significant amount, leaving little choice but to revert to the numerical treatment when investigating the interconnections between processes. It is for these reasons that the book concludes with a chapter on comprehensive numerical simulation.

In many ways, the approach adopted here is complementary to the more phenomenological approach. It is always important in a field which has very direct industrial applications to bear in mind how techniques such as those described here will be used, but it is essential not to lose sight of the fundamentals. There are serious safety implications; there are cost implications; there are moral implications; there are considerations of the appropriateness of the technology to the application under consideration. A proper respect for all these requires an understanding of the fundamentals.

This second edition has been revised and updated, and two extra chapters have been added, one on the use of lasers to cut glass, and the other on the concept of *Meta-Modelling*.

It is one of the problems of model building in science and technology, whatever the actual application of a model is to be, that there can be an uncomfortably large gap between the theoretical background and the desired outcomes of the model. There is a danger of the model becoming excessively complicated and unmanageable, when it should be possible to obtain what is desired more simply by the intelligent use of *model reduction*. This can be the key to successful numerical

implementation. The aim is to avoid any unnecessary complexity and make it easier to control error of whatever kind. Any mathematical–physical model is capable of suffering from unsatisfactory “reduction” from an excessively complex comprehensive description. Simplification can be achieved in a number of ways. These tend to fall into the following categories:

- phenomenological methods (e.g. rate equations with phenomenological coefficients);
- mathematical–physical methods (e.g. Buckingham’s Π -Theorem, asymptotic analysis, singular perturbation);
- numerical methods (e.g. proper orthogonal decomposition, principal component analysis);
- data-driven methods (e.g. meta-modelling, design of experiments).

The concept of meta-modelling is still rather unfamiliar, but it is a concept with great potential in many fields and certainly not least in laser technology.

We are all too well aware that this book does little more than scratch the surface of the problems involved in a fundamental understanding of the phenomena involved in laser materials processing and the ways in which theory and practice can interact. If we have provided ideas and information that cause others to test them experimentally or intellectually, agree with them or dispute them vigorously, and develop them further, we will consider that we have achieved our aim.

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