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REVIEWS

Chemical Oscillations and Instabilities. By P. GRAY and S. K. SCOTT. Oxford University Press, 1994. 453 pp. ISBN 019 8558643. £25.

The non-equilibrium chemical kinetics of reacting fluids have long been recognized by mathematicians as a rich source of nonlinear ordinary and partial differential equations on which to practise their analytical techniques. The equations often have such interesting behaviour, and such a large number of parameters to vary, that it is easy when analysing them to move far away from the physical situations in which they were spawned. The resulting theories may cause puzzlement to chemists and others who deal with the physical implications of the equations. On the one hand, they know that the range of parameters permitted by the chemistry can considerably restrict the theoretically possible range of behaviour. On the other, the sophistication of some of the analysis is such that it becomes difficult to relate the results to the possible outcomes of experiments. The authors of this volume, who combine considerable experience in the modelling of chemical kinetics with a firm understanding of the underlying scientific principles, have taken up the challenge of convincing the working chemist that nonlinear dynamical systems theory can be understood in simple terms, and can help with experimental interpretation. Their main method, expounded in the first 13 chapters, is to give descriptions of important chemical processes, motivate mathematical models, and then analyse the resulting equations with the aim of teaching techniques that can be applied to related problems. There are chapters on oscillations in closed isothermal systems, relaxation oscillations and excitability, autocatalysis in open systems, Turing structures, travelling waves and chaotic oscillations. The last fifth of the book takes a more experimentally based viewpoint, concentrating more on giving detailed explanations of how models are constructed for a few key systems. The introductions to some of the chapters adopt a nannyish tone, crisply informing the reader of what he or she should get out of the chapter 'after careful study'. I found this somewhat unnerving! In fact, as I argue below, I am not persuaded that the text completely succeeds in giving the required techniques in the best form for useful adaptation to related but not identical problems; nonetheless, many techniques are thoroughly described, and I would expect the book to have considerable value for chemists as a first source of guidance.

As a working fluid dynamicist, with a strong interest in nonlinear processes but little knowledge of chemistry, I find it a little difficult to put myself into the position of the putative chemist reader, long on experimental knowhow but unfamiliar with the mathematical tools. (The authors in their preface number people in my position among those whom they hope will benefit from the text, by learning about the beauties of the chemistry. In my view, however, they assume much more knowledge (and less 'fear') of chemistry than of mathematics, and devote their pedagogy to the latter; lacking any formal chemistry beyond age 16, I did not find the science easy to get into.) But I believe that what I would like most would be a relatively comprehensive theory, couched in simple language, accompanied by a large number of applications and examples of the theory so that it could be seen how to carry out calculations for particular model systems. For example, a large part of the book is devoted to reactions that can be satisfactorily modelled by second-order dynamical systems. The only non-stationary stable behaviour that can occur in this case is periodic oscillation, and this can arise from a steady state through a Hopf bifurcation or, rarely if at all in the present context, through a saddle-note bifurcation on an invariant circle. I would have liked to see, then, a general discussion of Hopf bifurcation and the stability of oscillations before beginning detailed analysis. The authors have adopted the alternative, 'discovery' approach, in which aspects of the general theory are only revealed through example. This sometimes makes it hard to get an overall view. It is a pity, for instance, that the crucial formula for β_2 derived by Hassard, Kazarinoff & Wan (*Theory and Applications of the Hopf Bifurcation*, Cambridge University Press, 1981) which gives the stability of oscillations near the Hopf point is just stated, without a reference; nor is there any simple description, in terms of a set of model equations, for the dynamics near such a bifurcation which would clarify the role of β_2. In consequence the formula looks like a piece of magic, and since there is no direct reference to its derivation the timid reader will not be inspired to apply it more generally. The authors clearly, and sensibly, wish to avoid frightening the reader off, but sometimes this is better achieved by a clear statement of what can be done rather than by conjuring up complex formulae without justification. A similar caveat applies to the discussion of the stability of homoclinic orbits on p. 225. *Why* does this depend only on the trace of the Jacobian at the associated saddle point, and not on any other details of the obit? In the absence of this information, the reader will be unsure whether the technique can be applied generally to all such stability problems. At this, as at several other points, the insertion of a reference to a fuller treatment would make a big difference to the book's usefulness. The reference list looks a little hoary, mainly due to the long interval between this volume's first publication as a hardback and its present paperback manifestation (at least 4 years). I can find no references in the text later than 1988. This means that recent results, for example on the permitted speeds of travelling wave fronts, are not addressed, leaving the reader with an impression of lack of progress which may not be justified.

My above remarks, which bear on the treatment of some of the analysis in the book, are not intended as a criticism of the whole enterprise. There is a great deal of material here, and much of it is very interesting and informative. It was amusing to read the discussion of the value of non-dimensionalization, universally accepted by fluid mechanicists for the analysis of multiparameter problems, but it seems not yet by chemists! The text makes it clear that the method is indeed valuable here. I particularly enjoyed the discussion of the zoo of possible steady-state bifurcations that can arise in some of the simplest reacting systems; those who look at convective instability for a living should be pleased that the initial bifurcations are not of this complexity. The chapter on pattern formation is also very clear and readable; it sensibly does not progress too far into the nonlinear regime. While there is sometimes mathematical inexactitude, there is plenty of enthusiasm and careful description as counterbalance. I can recommend the book as an appetiser to anyone wishing to enter the fascinating world of chemical oscillations.

M. R. E. PROCTOR

Coal Combustion. By J. TOMECZEK. Krieger, 1994. 167 pp. ISBN 0 89464 651 6. $49.50.

The average reader of *JFM* probably has little interest in coal. However, nowadays the technology of burning coal on a big scale is sufficiently developed for a lot of fluid mechanics to be involved. Gone are the days when large quantities of coal were burned by heaping it on a grate: instead, it is now either pulverised to tiny particles (diam. <

0.1 mm) and then blown with air as a jet into a huge combustor, or otherwise fluidized beds are used to burn or gasify coal. Thus China, which now mines more than 10^9 tonnes of coal each year, is reported to have 2000 fluidized beds burning coal. The most modern approach is first to gasify coal in a fluidized bed, which really is a combustor with insufficient oxygen. The result is that the coal's volatile matter is evolved and the solid carbon residue (called char) is only partially burned, giving off some carbon monoxide. Great care is taken to remove sulphur compounds (naturally present in coal) from these gases leaving the gasifer. After filtering out any fine particles, the gases are burnt in a gas turbine to produce electricity. In parallel with this, the char is burned in a second fluidized bed; this is oxygen-rich, in contrast with the oxygen-lean gasifier. Steam is raised in this second combustor fuelled by char from the gasifier, and electricity is thereby generated. Such technology can produce electricity with an efficiency of at least 50%, mainly due to the impressive efficiency of modern gas turbines. The large power stations built in the UK in the 1980s burn pulverized coal and have an efficiency of almost 40%. They also suffer from emitting the oxides of sulphur and nitrogen, which in turn lead to acid rain. Of course, the extent of such problems depends on the care taken to clean up the gaseous emissions.

This book has four chapters. The first gives a good but brief description of coal, its properties and particularly its thermal decomposition, to give off such gases as hydrocarbons, carbon monoxide, hydrogen, etc. when heated. It quickly becomes apparent that the author is from Poland, and is familiar with Polish coals, rather than those from e.g. Australia or South Africa and widely traded in international markets. The second chapter deals with the combustion of a single isolated particle of coal or char. Here the diffusion of oxygen to such a particle has to be considered, together with the products CO and CO_2 diffusing away from the coal. Often chemical reaction occurs after O_2 has diffused inside a porous char particle, which has a huge internal surface area of the order of one football pitch per gram. Here neither the chemistry nor the modelling is simple, because of both heat and mass transfer when coal burns with the liberation of heat, accompanied by a changing network of pores throughout the reacting solid.

Next there follows a large chapter on the combustion of pulverized coal; this is where fluid mechanics really becomes important. One must imagine a huge box, whose walls are punctured with holes, through which jets of air carry coal dust to be burned in a flame-jet. Recirculation of gases is important in the stabilization of the resulting flame; radiation is also important as a mode of heat transfer. Often extra air enters the combustor as a concentric jet with swirl. The more modern of these devices have many of these jet-flames entering the combustion chamber tangentially, i.e. almost parallel to the walls, because this can lead to smaller quantities of the oxides of nitrogen being produced. Although the problems are formulated very clearly, the most recent modelling work described was published in 1980; clearly there was a time in Poland when scholars were deprived of western literature. The final chapter is on the burning of coal in fluidized beds. This is a very thorough account of every aspect of this topic. It covers fluidization itself, as well as heat and mass transfer accompanied by chemical reaction in a fluidized bed. There are good descriptions of the hardware and also of the chemistry, especially of the production of the pollutants, NO_x and SO_x. This is where fluidized beds are in some ways at their best, i.e. in reducing the emissions of pollutants to acceptable levels.

There is a huge amount of information in this book, particularly on coal and its combustion on an industrial scale. At times I found the English hard to read; surely the American publisher could have found a devotee of Jane Austen to improve the

English. Perhaps inevitably, the book is a product of the cold war, in that it is very strong on East European authors, but weaker when covering Western writing. Nevertheless, the book fills a very real gap and provides an excellent primer for a newcomer to the subject.

A. N. HAYHURST

Groundwater Flow in Saturated and Unsaturated Soil. By H. ZARADNY. Balkema, 1993. 279 pp. $95 or £61.

Introduction to Numerical Methods for Water Resources. By W. L. WOOD. Oxford University Press, 1993. 255 pp. £40.

Sub-surface flow either in saturated aquifers or in the unsaturated zone above the water table is of significance both in agricultural and water resource situations. The importance of studying sub-surface flow has increased with the growing concern about pollution from sources such as fertilizers and chemical spills. Significant advances have occurred both in terms of the physical formulation and numerical modelling techniques but most of these advances are described in published papers. These two books, which approach the topic from different perspectives, provide valuable insights into the study of sub-surface flow.

Henryk Zaradny describes many original concepts which he has developed; they have led to pragmatic solutions for a number of important problems in saturated and unsaturated flow conditions. As I read through the book, I wished that I had been aware of his work when I was studying similar problems a number of years ago.

In the first part of the book Zaradny considers the basic mathematical formulation of the equations for the flow of water at the soil–atmosphere and the soil–water–plant interfaces with a thorough examination of the physical phenomena in the derivation of the equations and appropriate parameters and coefficients. For example, when discussing the various expressions used to describe the hydraulic conductivity of unsaturated soils, the author quotes eight alternative expressions from the world-wide literature.

Next there is a bridging chapter which introduces numerical methods; this is followed by an examination of six specific group of problems including unsaturated vertical flow, the time-variant flow of water towards drains, unsteady groundwater flow in dykes and dams, and sub-surface hillside seepage flow. For each of these topics, the author combines the formulation described in the first part of the book with appropriate numerical techniques to provide important solutions. Much of this material is based on detailed studies conducted by the author. He is Polish; in the translation of his work certain phrases are unconventional yet the meaning is always clear. His wide knowledge of literature from Eastern Europe and from the West greatly enhances the value of this book.

Dr Wood has a different starting point in preparing her book; she has collaborated with a number of scientists and engineers working on water resources problems. She has shared with them in formulating the problem and then devising numerical schemes to study the specific problems. The aim of the book is stated as the provision of *an elementary explanation of the mathematics needed to understand the simplest numerical models of surface and sub-surface flow most likely to be met in water resources computer packages*.

The description of the basis and application of the numerical methods is presented in a way that a committed non-expert can follow. Topics in the book include types of equations, the method of characteristics, finite difference methods, numerical solutions of surface flow and groundwater flow by finite differences, the finite element method, groundwater problems solved by finite elements, boundary integral methods, and certain aspects of water quality modelling.

Certain issues which are often neglected are stressed by the author, for example the difficulty in identifying appropriate initial conditions, convergence problems when there are a number of physical nonlinearities and the possibility of obtaining incorrect solutions due to the choice of an inappropriate numerical method. Examples are restricted mainly to projects in which the author has been involved; consequently the book does not have the wider perspective shown by Zaradny.

K. R. RUSHTON