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REVIEWS

Convection in Porous Media. By D. A. Nield and A. Bejan. Springer, 1992. 408 pp. DM128.

Modelling and Applications of Transport Phenomena in Porous Media. Edited by J. Bear and J.-M. Buchlin. Kluwer, 1991. 380 pp. $119 or £75.

These books are written in very different styles. In a sense they are complementary, though many workers comfortable with the content and presentation of one might find the other relatively unattractive.

The first is intended 'to provide a user-friendly introduction to the topic of convection in porous media ... (employing) only routine classical mathematics ... as a review and as a tutorial work'. It adopts familiar constitutive models for transport of mass momentum and energy in homogeneous saturated porous media, and uses them to solve boundary value problems by standard mathematical techniques. The book is tightly written, the applications are precisely defined and the approach, which relies heavily on dimensionless formulations, will be familiar to most engineering scientists. Within the range of topics chosen it is comprehensive, but it tends not to stress the real difficulties of reducing engineering or geomechanical problems to tractable mathematical form.

The second is a collection of separately authored chapters of greatly varying length and content, which has the paradoxical advantage of showing that there are different ways of looking at any given process. Much of it is very formal, and is concerned with setting up the basic continuum models (constitutive relations) that others might use. Three relatively specialized examples (two of these from the nuclear industry) are considered, covering boiling and drying. There is little connection between the various chapters. It should be noted that it is volume 5 in a series on Theory and Applications of Transport in Porous Media. I found considerable overlap with parts of volume 4: the first long chapter by Bear, which occupies nearly half of volume 5, is to some extent a digest of volume 4.

Neither is as balanced a text from the point of view of an engineering scientist as that reviewed earlier (*Theory of Fluid Flows through Natural Rocks*, by Barenblatt, Entov & Ryzhik, volume 3 of the Kluwer series, see *J. Fluid Mech.* 223 (1991), p. 663). Though Nield & Bejan stands very well on its own, it is primarily an academic textbook (and a very good one too); I hope that it does not sound churlish to argue that the limitations that academics impose upon themselves to maintain elegance and simplicity detract somewhat from the merit of their work as sources for engineers: real problems arise because of the inadequacies of our existing models, and unless this is emphasized there is a danger that engineers – trained by academics – will use inappropriate models. In the case of real porous media, the continuum assumption of an isotropic homogeneous undeforming medium with Darcy-like behaviour always has to be carefully examined: if the mathematical modeller does not carry out such an examination and assess the consequences of any departures from the assumption, the chances are that nobody will.

To this extent the rather arid and formal development of continuum equations is an important discipline. An understanding of the relevance of averaging processes and of their consequences for averaged continuum equations should always be emphasized in texts for engineers. I can therefore commend chapter 6 by de Marsily in Bear & Buchlin, where he provides a very brief account of the stochastic description of porous media, which includes information about the inherent heterogeneity of the medium. I can also commend §1.1.2 by Bear, in which he describes the modelling process: a failure to do this systematically often vitiates subsequent mathematical analyses and numerical computations.

Neither of the books makes any reference to fractured porous media (unlike Barenblatt *et al.*). Associated fractal effects cannot therefore be considered, and many real effects are eliminated.

Despite the mixed comments made above, I shall be very pleased to have both texts on my shelves; for those working directly in the fields concerned, they will prove very helpful, and for some Nield & Bejan will be a veritable mine of information and special results.

J. R. A. PEARSON

Electrostatic Spraying of Liquids. By A. G. BAILEY. Wiley, 1988. 197 pp. £24.95.
Electrostatic Atomization. By D. MICHELSON. Adam Hilger, 1990. 145 pp. £30.
Electrostatics: Principles, Problems and Applications. By J. CROSS. Adam Hilger, 1987. 500 pp. £50.

When asked to write a review of these books, I had to confess to having little expertise in the field of electrohydrodynamics but was interested to take the opportunity to learn something about the technology implied by the titles. It has to be admitted that this review represents therefore a limited viewpoint, although it may be one which reflects in a fortuitous way the state of the subject. There are many important areas of the field where understanding is only partial and theory has not reached the stage of accurate quantitative prediction. As in many engineering situations, application has out-stripped ability to analyse. To take a specific aspect, the harnessing of electrical forces for some practical purpose depends crucially on the extent to which the fluid, the liquid drops, the solid particles in suspension or whatever is of interest is charged. This often arises as a consequence of extremely complex mechanisms at interfaces, involving surface physics and chemistry. In the end the most that it may be possible to evaluate is that for a given size of liquid drop, say, there is a limit to the amount of charge which can be carried in accordance with Lord Rayleigh's classical stability theory (*Phil. Mag.* **14**, 1882, 184–186), but what can be achieved in the way of size and charge is an empirical matter.

Of the three books, I enjoyed most that by Professor Bailey. He sets the scene well in the early chapters with discussion of basic ideas on drop charging, formation of sprays, etc. Then the applications with which he is particularly concerned are those of crop spraying (evidently charged sprays give better coverage, reaching the parts other sprays cannot), paint spraying, ink-jet printing, propulsion by colloid thrustors and forming sources of ions. Some feel for the successful commercial developments is conveyed.

Dr Michelson's book is very similar in scope to that of Bailey, but she is more concerned to review a wide range of theory and experiment. A rough count of cited references shows the list to be longer than that in Bailey's book, but not as much as might be expected from the style. The review leaves a strong impression of uncertainty in the subject. An important example, because of its major role in the electrical production of fine sprays, is the ejection of fluid from the apex of a Taylor cone (the surface shape taken up by a meniscus at the end of a capillary tube when subjected to appropriate electrical stress, see G. I. Taylor, *Proc. R. Soc. Lond.* A **280**, 1964, 383–397). The phenomenon has been the cause of much interest, but Michelson can still only conclude that 'so far it has not been possible to formulate a satisfactory theory'.

The book by Dr Cross is much more ambitious in its scope than the other two. The stated aim is 'to provide a reference text which gives an introduction to the fundamental principles of electrostatics and describe the use to which electrostatic forces can be put and the problems created by unwanted static charge in industry'. To make the book accessible to a wide audience, Cross has tried to avoid using calculus, except that in the last chapter lost ground is made up for the mathematically literate. Occasionally a gradient or integration symbol creeps in at an earlier stage and there is cause for doubt as to whether these could be passed over as easily as is claimed in the preface. To readers of this Journal the approach may be a source of irritation, especially in the context of principles. On the other hand, in the contexts of applications and of problems, the book is a mine of information. Atomization and spraying feature prominently, but there are good accounts of many other areas, such as electrostatic precipitation, filtering, separation. Considerable space is devoted in a chapter on problems and hazards to the risk of fire from electrostatically generated sparks in flammable atmospheres.

M. D. COWLEY

Microhydrodynamics: Principles and Selected Applications. By S. KIM and S. J. KARRILA. Butterworth-Heinemann, 1991. 507 pp. £45.

Boundary Integral and Singularity Methods for Linearized Viscous Flow. By C. POZRIKIDIS. Cambridge University Press, 1992. 259 pp. £40.

The advent of high-speed computers has stimulated several developments in the theory of low-Reynolds-number flows, especially as applied to the motion of suspended particles and drops. Both books under review summarize some of the mathematical advances in the subject since the publication of Happel & Brenner's book in 1965 (*Low Reynolds Number Hydrodynamics*, Prentice-Hall).

Two techniques have proved popular and successful for numerical computation: the *multipole method* for the interaction of suspended particles having simple shapes, and the *boundary integral method* for rigid particles of more complex shape and for free-surface problems. Multipole methods represent particles by distributions of singularities at their centres, chosen so as to satisfy the boundary conditions in some averaged sense; they often provide accurate results for integrated quantities (like overall force or torque) for minimal computational effort. Boundary integral methods distribute singularities, of strengths to be determined, over particle surfaces, and are of computational value because they reduce the number of dimensions in the problem: a full three-dimensional flow field need not be calculated, only surface quantities are involved. A central feature of the method is the use of exact singular solutions of the Stokes equations for unbounded, or, occasionally, for bounded flow geometries. For rigid particles the task of determining the surface tractions (or Stokeslets) for a prescribed surface velocity proves to be ill-posed, and an alternative formulation in terms of surface stresslets is more amenable to computation.

Both these books describe the mathematics needed for the boundary integral method, and provide the singular solutions (and associated Faxén relations) that underlie it. Both books include short sections on unsteady Stokes flows (i.e. with inclusion of $\partial \boldsymbol{u}/\partial t$ but neglect of $\boldsymbol{u}\cdot\nabla\boldsymbol{u}$) but the interest is peripheral. The Pozrikidis book is in my view more readable on these topics. Pozrikidis also includes an account of elastic stresses and in particular surface tension at fluid–fluid interfaces, including non-axisymmetric shapes (though strangely enough surfactants are not discussed).

In other aspects however the Kim & Karrila book is more exhaustive, including an account of the multipole method with a more-or-less complete set of tabulated two-sphere results, a more thorough account of the distinction between mobility and resistance problems for rigid particles including crucially the topic of lubrication theory, and a discussion of parallel computer strategies for implementing multiparticle interactions. The title of their book is however a misnomer. 'Microhydrodynamics' should surely include a thorough discussion of Brownian motion and colloidal forces (given cursory treatment here). Additionally the 'Applications' unfortunately occupy only a small fraction of the (long) book, and appear to be selected in order to illustrate the mathematical technique rather than the other way round. There are few comparisons with experiment. In fact much better accounts of the applications of Stokes flow theory are given in the recent books by Russell, Saville & Schowalter and by van de Ven reviewed in *J. Fluid Mech.* vol. 222, 1991, p. 692.

Both books under review provide accessible summaries of mathematical techniques that together with standard numerical methods (which by and large are not discussed) enable the efficient computation of Stokes flows in complex geometries. I would not choose either as a textbook for undergraduates or even for graduate students, because its focus is too limited, but each within its limitations provides a convenient and useful consolidation of recent work.

J. M. RALLISON

Engineering Applications of Unsteady Flow. By P. H. AZOURY. Wiley, 1992. 383 pp. £50.

Introduction to Unsteady Thermofluid Mechanics. By F. J. MOODY. Wiley, 1990. 654 pp. £55.00.

When the Editor asked me to review these books he expressed surprise that any book should be concerned with unsteady flow alone. After reading them I find myself convinced that no book could cover all unsteady thermofluid-dynamics; for the books by Azoury and Moody appear initially to be wide ranging, yet on further study are found to be somewhat restricted. Both authors concentrate largely on internal flows but I could not find reference in either volume to the work of von Kármán & Sears (1955) on unsteady flow past aerofoils, surely the classic work not only for 'external' aerodynamicists, but also for those concerned with turbomachinery fluid mechanics, inevitably unsteady.

Azoury's book brings together a variety of unsteady flows, mainly one-dimensional and compressible, and details their many applications. After a brief but fascinating historical account of engineering developments including applications to reciprocating engines, pressure exchangers, hydraulic rams and ocean wave machines, the author discusses the fundamentals of energy transfer (of both heat and work) in unsteady flows, presenting the relation between the substantial derivative of stagnation enthalpy and pressure variation with time,

$$\frac{\mathrm{D}h_0}{\mathrm{D}t} = \frac{1}{\rho}\frac{\partial p}{\partial t},$$

for inviscid adiabatic flow, showing that stagnation enthalpy change occurs only in unsteady flow. He places a good, brief discussion of the method of characteristics in an appendix; but for most readers it would have been helpful to have had that material well forward in the main text as part of the more general discussion of pressure and expansion waves, before the details of specific applications that follow.

The best part of the book relates to the description of pressure wave machines (or dynamic pressure exchangers) – devices in which flow at a high pressure transfers energy to a low-pressure flow, raising its pressure through wave action. These machines can usually be described in terms of one-dimensional compressible flow. Their development has been fitful, but now after a long period of experimental work Asea Brown-Boveri (ABB) have introduced the Comprex as a supercharger on an automotive diesel engine, some forty to fifty years after its inventor Claude Seippel filed his original patents. (But I was delighted to read Azoury's warm appreciation of Pearson's parallel development of a pressure wave engine – a kind of unsteady flow Otto cycle engine – achieved alone, in his garage at home. Unsteady flow seems to attract independent characters like Pearson.)

Equally good are Azoury's accounts of the utilization of pressure wave effects in internal combustion engines – ramming of entry air, scavenging of exhaust gas, and the unsteady flow interaction between superchargers and engine cylinders.

Less satisfactory is the discussion of what Azoury calls the cryptostatic pressure exchanger – in which the flow is steady in a moving reference frame, but unsteady in an absolute one. Indeed the uniform flow entering a rotating row of blades (of finite spacing) satisfies this description, and the author might have been expected to include reference to Preston's fundamental analysis of this flow (Preston 1961), which illustrated Dean's argument (Dean 1959) that work transfer in a turbomachine is essentially an unsteady phenomenon. (The brief reference to rotating stall may somewhat confuse the reader not familiar with turbomachinery fluid dynamics.)

Azoury's book tends to emphasize the work of Europeans in this field. Spalding's group at Imperial college (of which Azoury was a member), Benson's team at UMIST and the ABB engineers all figure prominently, both in the analysis of wave effects in I.C. engines and in the development of computational methods for their solution.

The second, larger book by Moody does not contain any references to this work, yet there is substantial overlap in content in many areas. Most, but not all, of Moody's book is related to one-dimensional unsteady flow, with four major chapters devoted to (*a*) hydrostatic incompressible surface waves (with pressure approximated to local hydrostatic head) and (*b*) pipe flows (incompressible and compressible), of small and large amplitude in each case. These chapters contain direct analogues of many of the compressible flows described by Azoury, but these are dealt with more fully in Benson's substantial volume (Benson 1982) on the thermodynamics and gas dynamics of internal combustion engines (which includes discussion of many similar problems, e.g. pipe enlargements and contractions, pipe junctions, effects of friction, etc.) and in the long chapter on one-dimensional waves in the book by Lighthill (1978).

In addition to these four comprehensive chapters Moody has introductory sections on unsteady thermofluid dynamics (more 'fluid' than 'thermo'), an odd but interesting chapter on 'convective propagation' (including examples of fluid jet development and heat transfer in pipes), and he then winds up with some multidimensional cases of unsteady flow. The final chapter is a miscellany which might be described as 'unsteady flows I have known'.

There are two striking features of Moody's book. The first is the extraordinary range of examples – both worked and unworked problems – which makes it a useful source for the teacher of fluid mechanics. (To quote just a few of the several hundred examples – pressure vessel blow-down, fluid jet 'shocking', liquid sloshing during an earthquake, spherical water hammer propagation, and a manometer mounted on a spring-mass system!). Moody has clearly had a life-time's experience in this area, as a practical engineer with General Electric involved in a great variety of industrial problems. He has called on that wide experience in his adjunct university teaching and has now done so in compiling this volume.

The second feature is that this very wide range of interest leads to some lack of focus in those parts of the book outside the four chapters on waves. This is coupled with some unusual definitions, new to this reader. For example, it is quite logical to distinguish between unsteady flows in which pressure waves dominate ('propagative' flows) and those in which a representative propagation time is small compared with a disturbance time (e.g. the time for a valve to open). Moody calls the latter 'bulk' flows, and gives some interesting examples of them (e.g. the draining of incompressible fluid from containers of various shapes).

These two books will form useful additions to departmental libraries, and indeed to personal book collections of engineers concerned with unsteady flows in practice. Both distil a substantial amount of knowledge and experience accumulated by the authors. However, as teaching books they may leave something to be desired, for two reasons. Firstly they tend to divide rather than integrate incompressible and compressible flows; secondly the lead-in to the subject through the basic fundamentals is relatively brief in each book.

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J. H. HORLOCK

The Tubular Thermosyphon: Variations on a Theme. By G. S. H. LOCK. Oxford University Press, 1992. 326 pp. £45.

The topic of natural convection is dealt with in many books which consider the wider topics of fluid dynamics and heat transfer but not with the same emphasis as *Variations on a Theme of the Tubular Thermosyphon*. This book stems from Professor Lock's lifetime research on the thermosyphon, which encompasses small-scale experiments, numerical calculations and innovative applications of natural convection in confined flows. It considers the tubular thermosyphon with and without condensation and evaporation, and includes a chapter on rotating flows where centrifugal forces may replace or add to gravitational forces. Devices such as the heat pipe and aerosyphon are described in a final chapter.

The readership of the book is likely to comprise those with a specific interest in the thermosyphon and, perhaps to a lesser extent, in the influence of body forces in general. The writing of the book has been a labour of love, and the content and sequence of presentation reflect this personal flavour. It is not a textbook, so that it is unlikely to find favour in undergraduate and postgraduate teaching, except where projects provide a direct need.

The review of applications of natural convection in chapter 1 is extensive and interesting and provides a challenge to the reader to think of those that are not included (the domestic back-boiler and radiation water-heater is one). Equations and some simple analysis are provided in chapter 2 and are extended to encompass two-phase flows in chapter 3. A wide range of geometric boundary conditions are represented by the results of the two chapters, including aspect ratio, angle and simple non-rectangular shapes, and are frequently in the form of flow patterns, heat flux and temperature as functions of location, pressure and Reynolds number. The use of dimensional quantities is unusual, and the Reynolds numbers are frequently associated with non-turbulent flows with correlations introduced to represent many of the heat transfer results. The flow patterns in these and the following chapter are often exciting and thought-provoking.

Chapter 4 is concerned with rotation and the replacement of or addition to gravitational forces for single- and two-phase flows. The inception of much of the research at the University of Durham in the 1950s suggests that turbine-blade cooling was one of the driving forces but, perhaps a little surprisingly, this subject is not considered although chapters 4 and 5 emphasize simpler related geometries. Turbulent flows are not dealt with explicitly, so that the effects of the body forces on turbulence are not considered,

The selected bibliography is extensive and useful. This is an interesting and readable monograph which meets the author's description of a comprehensive introduction and reflects his fascination with the thermosyphon.

J. H. WHITELAW