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REVIEWS

Dense Gas Dispersion. Edited by R. E. BRITTER and R. F. GRIFFITHS. Elsevier, 1982. 254 pp. $74.50.

Over the past 5 or 10 years there has been a growing concern, heightened by a number of well-publicized accidents, about the sometimes disastrous consequences of spills during the storage, handling and transport of hazardous materials. The consequences of such spills are exacerbated and less predictable when the material released forms a denser-than-air mixture. There has been a concomitant growth in both basic and practical research aimed at understanding and modelling the dispersion of dense-gas mixtures.

This book, published as a special issue of the *Journal of Hazardous Materials*, describes up-to-date developments in this field. The general style is that of a research monograph rather than a definitive work, with articles invited from leading researchers in the field. Individual papers vary across the spectrum from review articles to research articles and are generally fairly independent with minimal cross-referencing. There is thus some repetition of basic material (although usually from a slightly different viewpoint) but a broad range of topics is covered (field experiments, wind-tunnel experiments, modelling approaches, comparisons between models and experiment and fundamental theoretical considerations). Rather than attempt to review each article separately it is probably more useful to give a brief summary of these main topics.

The book begins with an introductory article by the editors in which they draw attention to the special problems associated with release conditions and the wide range of possible factors which determine the initial density and configuration of a dense gas cloud. They also pinpoint the essential complication in the dispersion process, that is that dispersion is due to the *combined* effects of the background flow and buoyancy-generated flow, and, although individually these are reasonably well documented and understood, their interaction produces a complex and interesting problem.

In foreshadowing the variety of modelling techniques that are in use and which are discussed later in the book, the editors make a cautionary note on the use of eddy diffusivities and point to the need to give more attention to a range of 'non-standard' problems, including the effects of topography, buildings and other surface features.

There are two articles concentrating on field experiments. That by Puttock, Blackmore and Colenbrander gives a review and useful tabulation of field experiments and a description and brief preliminary results for tests conducted at Maplin Sands by Shell. Criteria for density effects to be important are discussed as are the problems inherent in scaling up to full-size releases. The article by Koopman *et al.* is a description and analysis of the BURRO series of experiments performed at the Naval Weapons Centre, China Lake. Of the eight experiments conducted, only one was buoyancy-dominated. Representative results for various features of the gas cloud are presented (concentration contours, distance to the lower flammable limit) but perhaps most interesting is figure 15, which shows (peak/10 s mean) concentrations and gives an indication of the large variability in concentration. Indeed figures 19 and 21 show that there is considerable variance in the concentration signal on a timescale of 10 s, and suggests that a longer averaging time might be appropriate for measuring mean concentration levels.

Meroney reviews wind-tunnel modelling of a wide range of circumstances associated with dense-gas transport. He discusses modelling criteria and scaling difficulties before summarizing wind-tunnel measurements for dense-gas releases from elevated and ground-level sources and for their interaction with surface features and buildings.

Four papers deal with dense-gas dispersion models and comparisons with experimental data. Models used can generally be categorized as Gaussian-plume models, slab models and K-theory models. The paper by Blackmore, Herman and Woodward reviews 15 current models, giving details of mechanistic features, applicability, different types and geometries of release, the ease of availability to users and the degree to which calculated results have been compared with field data. Ermak, Chan, Morgan and Morris compare models in each of the three categories with data from the BURRO series of experiments. Woodward, Havens, McBride and Taft compare data from a number of different experiments with five models including representatives from each category, while Havens gives a description and sensitivity analysis for the SIGMET-N model (a K-theory model). Woodward *et al.* found different sets of data were better fitted by K-theory and slab models, while Ermak *et al.* found BURRO data to be fairly well represented by both K-theory and slab models. In both sets of comparisons, Gaussian models performed poorly.

Griffiths and Kaiser review work relating to accidental releases of ammonia. The interesting feature there is the production of a denser-than-air cloud from a gas with a lower molecular weight than air. Processes that occur during release and that depend on the mode of release (vaporization, cooling, droplet formation, air entrainment) are critical. In addition the authors touch on complications such as surface features and dry deposition.

Chatwin discusses the importance of concentration fluctuations about the mean, a topic which is of particular interest in dense-gas dispersion, but is also of more general importance. Two of the chief hazards encountered in dense-gas accidents are those of fire and explosion. The author points out that quite a different picture of the risk of these events is obtained when the inherent variability of the concentration field is taken into account. Figure 15, 19 and 21 in the article by Koopman *et al.* indicate the extent of this variability. Chatwin urges that much more attention be given to a fuller statistical description of the concentration field through theoretical and experimental work on the probability density function of concentration.

The closing article, on future directions of research, is by McQuaid. He emphasizes that the principal deficiency at present is the absence of a body of reliable data. He distinguishes between the formation and dispersion stages and discusses the advantage of separating these by conducting dispersion experiments with premixed dense gases, as has been done in the Health and Safety Executive programme. He also suggests that greater use might be made of remote sensing systems (such as LIDAR) to reduce the cost of experiments dependent on a fixed array of sensors.

To conclude, the appearance of this book is timely because a considerable proportion of the research has been carried out in industry or by various public authorities with the result that much of the literature consists of internal and conference reports. The present collection of articles bring the whole subject much more into the open literature.

At $74.50, the volume is expensive, and in view of the effort being expended in the field may date fairly quickly. Unless closely connected with the field, individuals will probably not want to buy their own copy of the book, but certainly all libraries servicing air quality, industrial safety and turbulent dispersion research should buy it.

B. L. SAWFORD

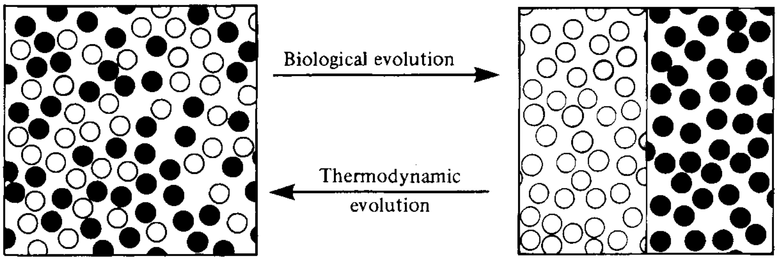
Instabilities, Bifurcations and Fluctuations in Chemical Systems. Edited by L. E. Reichl and W. C. Schieve. University of Texas Press, 1982. 427 pp. £26.25.

The past decade or so has seen an explosive growth of interest in the theory of chemical systems far from thermodynamic equilibrium. One reason for the fascination of many workers with this new field is that it deals with evolution contrary to our psychological arrow of time. Indeed our usual daily experience is embodied in the second law of thermodynamics. We are used to the spontaneous mixing of different chemical species, to the abolition of order and structure. The entropy of the system can be expressed by Boltzmann's expression $S = k \ln \Omega$. A natural process is one in which there is an increase in Ω, the number of complexions which are accessible to the system. An evolution which starts from a state of maximum 'mixed-upness' and ends in a differentiated system will appear to the usual observer as a film played in reverse, and hence 'unreal'. And yet it is this 'unreal' evolution that is the centre of the 'non-equilibrium chemistry'.

In fact biological evolution seems to offer such 'unreal' evolution. Indeed the formation of a differentiated adult organism, starting from a single cell, the zygote, presents a transition from a state of maximum randomization, symmetry and indistinguishability, to a state with maximum segregation, broken symmetry, order and complexity. It presents a transition from high entropy to lower entropy – an apparent contradiction of the second law. Life thus appears as a transition to the most improbable state. The contrast between biological evolution and thermodynamic evolution (shown schematically in figure 1) was a major scientific and philosophical problem, so much so that some scholars postulated that biology has a special status and cannot be explained by the laws of physics and chemistry alone. In fact evolution towards structure and organization characterizes not only ontogenesis but also phylogenesis. In this attempt to provide a rationale for Darwinian evolution, the well-known philosopher Herbert Spencer adduced the hypothesis that the driving force of evolution is the transition from homogeneous to non-homogeneous structures, a transition which he considered equivalent to the development of organizational complexity. Similar ideas were expressed by the philosopher Henri Bergson.

The above discussion poses the question whether we can explain the transition from homogeneity to heterogeneity within the second law of thermodynamics. First let us consider a chemical system in thermodynamic equilibrium. Such a system is in a state of maximum entropy and is known to present a Le Chatelier moderation principle. It means that any fluctuation around thermodynamic equilibrium will not be amplified and therefore the system will remain stable in the homogeneous state. Let us now consider a non-equilibrium chemical system. We consider first the linear range close to thermodynamic equilibrium, where Onsager's theorem $L_{ij} = L_{ji}$ applies ($J_i = L_{ij} X_j$, and J_i and X_i are the thermodynamic flow and force). Here again we get a moderation theorem, the theorem of minimum dissipation, or of minimum entropy production. Again the non-equilibrium homogeneous steady state cannot become unstable.

It was left to A. M. Turing in his epoch-making paper provocatively entitled 'The chemical basis of morphogenesis' to show that a chemical non-equilibrium steady state can become unstable provided that system operates far enough from thermodynamic equilibrium. Breakdown of symmetry and homogeneity occurs when the distance from chemical thermodynamic equilibrium reaches a critical value. Thus the contradiction between thermodynamic and biological evolution is solved by observing



that both are governed by the same physical laws, namely the law of mass action and Fick's law, but, whilst for biological evolution the distance from thermodynamic equilibrium increases, it decreases for thermodynamic evolution. This distance from chemical thermodynamic equilibrium appears as a bifurcation parameter in the reaction-diffusion equations which could be written as follows:

$$\frac{\partial X_i}{\partial t} = f_i(X_j) + D_i \Delta X_i \quad (i,j = 1, \ldots, n). \tag{1}$$

What does a non-equilibrium constraint mean in the context of chemical systems? At thermodynamic equilibrium all forward and reverse reactions balance. For the reaction $A+B \underset{k_2}{\overset{k_1}{\rightleftharpoons}} C+D$, we have $k_1[A][B] = k_2[C][D]$. Non-equilibrium constraint implies the constant supply of reactants and removal of products from the system. A non-equilibrium chemical system is thus an open system. A reactant concentration is typically the bifurcation parameter.

Turing's work could be considered as the first essay in the theory of chemical instability, which is in many ways analogous to the more established 'hydrodynamic stability' theory in fluid mechanics. The analogy does not end in the common mathematics such as linear stability analysis. For example, just as in the Bénard phenomenon, instability occurs in (1) as a result of competition between two flows. Chemical reaction is the transforming flow creating non-uniformity. Diffusion is the moderating flow destroying non-uniformity. This is in analogy to the interaction of a transforming convection flow and a moderating heat flow in the Bénard case. Reorganization and instability set in when the pressure of the transforming agent is too great.

It is interesting to note that, although the monumental work of Turing was published in 1952, it was not substantially discovered until the second part of the sixties when groups of chemical engineers in the New World and of physical chemists in the Old World began to analyse Turing's work. The seventies has seen ever-increasing interest in (1). Various abstract chemical mechanisms representing subcellular and cellular biology were analysed. Systems of various geometries, dimensions and boundary conditions were considered. The solutions of the reaction-diffusion equations include stationary and non-uniform states, travelling and standing waves, and homogeneous time-dependent self-sustained oscillations.

Many biological fields were analysed in the context of non-equilibrium chemical reaction-diffusion systems. These include cellular differentiation, biological morphogenetic pattern formation, metabolic and genetic control, neurology, excitable membranes, biological clocks, pre-biotic evolution and the origin of life and more. Also analysed were non-biological laboratory chemical systems. Here the Belousov–Zhabotinski reaction has occupied most of the attention.

In fact the present fascination of workers with nonlinear reaction-diffusion systems partly stems from the many apparently unrelated fields where they appear. Reaction-diffusion systems appear in chemical engineering, in electronics, and in semi conductors. They appear in solid-state physics representing the interaction between point defects and their diffusion. They can even appear in various ecological–sociological contexts that hitherto were not quantifiable. Thus various micro-organisms are organized into honeycombs much like the Bénard type. Such an aggregation is of interest in developmental biology. The Lotka–Volterra model of predator–prey relationship in fish is another ecological example. In fact even a human society, say at the national level, could be represented by reaction-diffusion system. For example the reaction, governed by the law of mass action, could represent the transformation of raw materials to products. The assumption of Fick's diffusion law of goods is also reasonable here. Thus a society that encourages a high degree of production and spending, with an associated high degree of influx of raw material and removal of waste, is operating beyond instability and will present a non-homogeneous distribution of goods. The result is that 'capitalistic' society is bound to have a high proportion of 'haves' and 'have nots'.

Of greater interest to the readers of *JFM* is the similar mathematics used for reaction-diffusion systems and the usual fluid mechanics systems. This goes beyond the linear stability analysis. Thus the removal of the indeterminacy of the linear problem by including in the analysis the nonlinear terms is similar in both fields. In both fields the bifurcation parameter is the distance from thermodynamic equilibrium.

The book reviewed here grew out of a workshop on 'Instabilities, Bifurcations and Fluctuations in Chemical Systems' held in the University of Texas at Austin in 1980. Althhough some of the papers are introductory in character, it is perhaps best read after or in conjunction with *Self Organization in Nonequilibrium Systems* by G. Nicholis and I. Prigogine (Wiley, 1977). A shorter introduction to the field is the article by J. I. Gmitro and L. E. Scriven, in *Intracellular Transport*, ed. K. B. Warren (Academic Press, 1966, pp. 221–255). Or even the original article of Turing itself.

The volume reviewed includes works on the effects of size and external fields on bifurcation by G. Auchmuty and D. Konepudi respectively. R. B. King describes a method of categorizing nonlinear chemical systems by means of switching theory, and B. Bunow and J. P. Kernevez describe how to trace bifurcation branches numerically. M. L. Smoes describes experimental aspects of ferroin-catalysed Zhabotinskii reaction. An interesting article by Ortoleva *et al.* deals with mechanisms of bio- and geo-pattern formation and chemical signal propagation. Patterning phenomena in rocks is presented with the help of many photographs. We should emphasize at this point that some equilibrium patterns observed in nature, e.g. in geology, may well have been non-equilibrium dissipative structures created by reaction-and-diffusion, and were later 'fixed' by the development of covalent bonds, and crystallization. It should also be noted that reaction-and-diffusion occurs in soil sciences and that this science still awaits the reaction-diffusion theoreticians. J. Hiernaux and T. Erneux discuss pattern formation in morphogenesis, whilst A. Nazarea presents critical-size estimates for the onset of instabilities in membrane bond reactions and monolayer arrays of cells. T. Darden compares deterministic and stochastic models of enzyme kinetics.

The last group of articles deals with fluctuations and stochastic theory. The article of M. Malek Mansour and C. Van den Broeck is a clear introduction to fluctuation theory in reaction-diffusion systems. The central problem here is, as in equilibrium phase transition, how very local fluctuations are correlated over the macroscopic distances of the system, so that in the critical point the fluctuation does not regress but is amplified, and a macroscopic transition to a new state occurs.

In conclusion, although some papers in the book are up-to-date reports of a somewhat specialized nature, others are more of the nture of a general exposition, and the book as a whole demonstrates the great variety of experimental domains and theoretical subjects that can benefit from the bifurcation theory of reaction-diffusion equations. It is also to be hoped that reviewing the field and the book in the *JFM* will contribute to greater awareness of the part of fluid dynamicists that non-equilibrium chemistry and fluid mechanics share common mathematical methods and physical principles.

Y. SCHIFFMANN

Handbook of Multiphase Systems. Edited by G. HETSRONI. Hemisphere/McGraw-Hill, 1982. 1492 pp. US $64.50.

The subject of multiphase flow covers a variety of topics: gas–liquid flow, which occurs for example in boiling and condensation; gas–solid flow, which occurs in pneumatic conveying, sedimentation and fluidization; and liquid–liquid flow, which occurs in solvent-extraction processes. More-complex systems (more than two phases) are possible, but this handbook is almost exclusively concerned with problems in two-phase flow. Two-phase flow is evidently of some interest to the contributors to *JFM* as typically about 5 % of the papers are directly on two-phase problems (for example sedimentation and the behaviour of gas bubbles in liquids) and a further 10 % on less directly related problems (for example water waves, jets and free surface flows).

It will already be evident that two-phase flows are industrially important. It is not surprising therefore that much work has been done on these flows and been published in the chemical, mechanical and nuclear engineering literature. One of the most active areas (and the most conspicuous by its absence from *J.F.M.*) is that of the safety analysis of liquid-cooled nuclear reactors. This is a challenging subject involving the formulation and solution of a number of nonlinear partial differential equations in complicated geometrical systems. It is possibily not surprising therefore that much of the published work is of the correlation type, and relatively little is on the fundamental physics of the situation. The difficulty lies in the fact that, although the fluids are usually Newtonian, the flow is almost always turbulent, there is often evaporation or condensation with thermodynamic non-equilbrium between the phases, and the interaction between the phases (for example the interfacial shear stress) is incompletely understood. Thus the equations representing conservation of mass and energy and the force equation for each of the phases can be written without too much difficulty, but they contain so many unknown terms and their unambiguous solution is so difficult that for most practical cases engineers have to resort to the empirical correlation approach based on experimental data which is often inadequate. We are thus faced with a dilemma: the rigorous solution of the equations is too difficult and the correlation 'solution' is very limited. To take a very simple example; it is not possible to calculate the pressure gradient in an adiabatic gas–liquid flow in a straight smooth circular tube from a correlation with an accuracy better than 30 %. Solution of the basic equations can only give a result if some equation or correlation for interfacial friction is included.

With this background then, where does this handbook fit into the picture? The statistics are certainly impressive: nearly one and a half thousand pages, nearly two kilograms in weight, and containing contributions from 43 authors. However, what does it contain and what readership is it aimed at? The book is divided into ten main sections (each with its own reference list and nomenclature) of widely differing length:

1	Basic principles	273 pages	7	Conveying	52 pages
2	Liquid–gas systems	136 pages	8	Fluidization	240 pages
3	Gas–solid systems	55 pages	9	Separation	160 pages
4	Liquid–liquid systems	46 pages	10	Measurement techniques	181 pages
5	Condensation	64 pages		Index	37 pages
6	Boiling	259 pages			

As usual the dust jacket claims that the book will be useful to almost everyone: industrial designer in the process, chemical and nuclear industries, student and teacher. There does seem to be some justification for this claim, as the book will form a valuable work of reference for all three classes of people. It does not, however, claim to be (and indeed is not) any kind of introductory text-book. It should be emphasized that, in spite of its length, the book does not attempt to cover all aspects of its subject. For example you will not find listed every method of calculating the pressure gradient in gas–liquid pipe flow. It is also not explicitly a design manual, though some sections do carry explicit recommendations for design rules.

In terms of the division of work on two-phase flow into the basic equations and correlations, the first section on 'Basic principles' covers the fundamental conservation and force equations, and the remainder of the book is concerned mainly with more or less empirical correlation approaches. The distinction is not entirely clear, because some of the later sections do contain some material of a basic nature. Readers of *J.F.M.* will probably be most interested therefore in the first section. Unfortunately I found this section the most disappointing one in the book. The work is treated in a very rigorous manner and, it sometimes seems, the connections with reality and the rest of the book are only tenuous. There are a number of subsections dealing with how the full two-phase equations can be simplified for practical pipe flows. Even here there are no examples concerning what results the various simplifications can give and no information about which simplifications give equations which are soluble in practice. My ability to understand the first section was not always helped by the nomenclature employed, for example one simple equation concerning interfacial areas is given as

$$\langle\!\langle (r) \rangle\!\rangle_3 \equiv \overline{\rceil_3(t)} \qquad [1.2.141]$$

The major strength of this book lies in its treatment of the more empirical type of work. The authors obviously have a thorough grasp of their subjects and communicate it well. In general the good features of the book are fairly obvious: it is comprehensive and up to date. These features make it a valuable addition to any institution library and a worthwhile purchase for some individuals. The weaknesses are less obvious and can most conveniently be listed.

(1) The index is not very adequate, and is not always helpful if you do not know exactly what to look up. Empirical methods are sometimes indexed under the name of the author, but not always: it seems rather arbitrary.

(2) Even in this comprehensive work, some subjects are unaccountably absent, or at least the index did not guide me to them. Thus in the long section on boiling there is little mention of the important topic of the boiling of mixtures of liquids. In the section on separation, there is no mention of the important and special problems of separating a liquid and a condensable vapour. Most surprising perhaps, there is

virtually no mention of critical flow of two-phase mixtures even though there is a substantial subsection devoted to the topic of accident analysis of nuclear reactors.

(3) There are inconsistencies between the main sections, and much less often within one of the main sections. These inconsistencies are not only of nomenclature (even for such commonly used variables as tube diameter, void fraction, enthalpy of vaporization and mass flux) but also of definition and interpretation (for example different defining equations for the commonly used Martinelli parameter in pressure gradient and void fraction correlations are found).

(4) There are good cross-references within main sections in the book, but very few between the main sections. This is most obvious, as already has been noted, for the first section on 'Basic principles': this material never seems to be used elsewhere in the book. The lack of cross-references between main sections has unfortunate consequences. The close similarity between gas bubbles in liquids and bubbles in fluidized beds is not identified. Again, because of this omission, some subjects are covered twice, for example critical heat flux in pool-boiling systems. These are no doubt consequences of the multiple authorship.

(5) There are a few misprints, but for a long and complex book I noted relatively few. A few of the diagrams are too small to be of much use, but the general standard of the illustrations is high.

These faults are perhaps easy to list, but when set alongside the achievement this book represents they are rather trivial.

What does come out of looking at this book is that there is a pressing need for a clear exposition of the basic equations of multiphase flow. Such an exposition ought to include an account of what simplifications are needed before the equations can be solved even for a simple case of practical importance, and the kind of results that can be obtained as result of these simplifications.

P. B. WHALLEY

Circulation in the Coastal Ocean. By G. T. CSANADY. Reidel, 1982. 279 pp. $52.50.

The number of texts on physical oceanography has expanded rapidly during the past decade, indicating the advances in our understanding of the ocean. Nearly all these attempt to encompass most of the field within a single book. A suggestion that the subject is coming of age is the appearance of this book, which is devoted only to a *subset* of physical oceanography. The book grew out of a graduate course on coastal dynamics given by the author at Woods Hole Oceanographic Institution on longer than tidal-period motion in enclosed or shallow seas, and the text is aimed at a graduate or research audience.

When one sees a new textbook, one naturally asks 'why was this book written, and what does it try to achieve?' I think the length of the book indicates clearly the reason for its existence: there is a large body of work on coastal processes, now sufficiently detailed to be difficult to cover in a textbook of more general scope. As to what the book sets out to achieve: this is a synthesis of theory and observation, suitable for those inclined towards industry and towards research. I was pleased by the attention given to frictional processes, normally given short shrift in more theoretical texts but unavoidable in treatments of shallow seas; but still I would have liked to see even more detail given to the topic.

In his foreword, Csanady apologizes for the natural bias towards his own results, and he endeavours to quote key original papers when appropriate. In this, I feel he was not wholly successful. Many times, the lack of recent references which would help the student understand a topic more clearly was noticeable; not everyone has easy access to the Science Citation Index! For instance, Krauss's 1966 work on internal waves is the only reference given for vertical normal modes, whereas most of the key work took place subsequently. Another bias is towards analytical rather than numerical results. I think this has produced rather too many very complicated analytical solutions when a few statements about clearer problems, and some well-placed numerical results, might well have conveyed more insight.

The book consists of eight chapters (although in the contents chapter 6 and 7 have the same title, one of only very few typographical errors). Chapter 1 gives a brief introduction to the equations of motion, and quite reasonably assumes a fair amount of familiarity with fluid dynamics. The treatment seemed a little too brief in places. The impression is given on cursory reading that the density of sea water is controlled by salt and of fresh water by heat; Reynolds stresses receive half a page; and, indeed, I would have liked to see all the frictional processes discussed in more depth.

Chapter 2 examines the effect of a wind stress at inertial timescales. Here, as in several places, the treatment begins with a complicated situation and ends with a simple one: the first solution involves a sum of Fourier modes (which in my opinion conceals the fundamental nature of the deformation radius) and only later looks at a simple infinite-coastline problem. I would have preferred the order inverted. Again, Kelvin waves appear in a complicated expression and are then studied in detail. But this is merely personal preference: the strength of the material is the constant attention given to questions like 'what is going on with the frictional terms while the wave propagates?', so often omitted in texts that strive for neat solutions. Life in the real world is seldom neat, and Csanady is at pains to get this across.

Chapter 3 introduces stratification effects. Again, I found the attention to high-level algebraic detail distracting: the model chosen for stratification (though realistic) produces a transcendental eigenvalue problem needing numerical solution involving seven different symbols. Surely the sinusoidal case of constant buoyancy frequency (although unrealistic) would convey information to the student? The chapter continues with a clear description of the two-layer approximation and builds up an impressive collection of solutions to initial-value problems. At the end, the internal Kelvin wave appears, but again with a very messy set of formulae (but accompanied by a clear discussion).

Chapter 4, on the effects of topography, is very well handled. The effects of seiches, coastal waves, and 'vorticity waves', or topographic Rossby waves, are examined, with many examples. The problems of the interaction between topography and stratification are well discussed, with emphasis on the lack of knowledge in the area.

Chapter 5 discusses transient effects, and provides one of the two chapters that were for me the strong point of the book: discussion in detail of observations, and their relation to the foregoing theory. A wealth of material is covered here.

The remaining chapters cover essentially steady phenomena. Chapter 6 discusses the fundamental problem of friction. While the material covered is clear and concise, I was a little disappointed not to find a really detailed debate about realistic ways to handle friction. No matter whether the resulting models would be too difficult to solve, in a book as practically oriented as this it would have been valuable to criticize our views on friction. Nonetheless, the problems treated are distinctly clearer and easier to follow than those in the earlier part of the book, although sometimes lapsing into complexity. This obviously worries the author, who notes ruefully on p. 186 that 'the complex calculations discussed in the previous sections relating to relatively minor details of interior velocity in turbulent flow...become a rather meaningless exercise'.

Chapter 7 returns to thermohaline circulation, beginning with frontal adjustment. Again a very complicated example is given, which tends to obscure the physics; surely a simpler one would have sufficed? The problem of convection is raised, and approximations cleverly introduced to handle its complexities (though I would have liked to see a useful diagnostic tool like 'thermal wind' not relegated to the last line of one paragraph). Finally, chapter 8 presents the other synthesis of observation and theory, by examining steady-state structures. Storm responses, sea-level variations and moored instruments are all treated, again with the emphasis on extracting the physics of the situation.

In summary, this book fills an important gap in the oceanographic literature. In places I would have liked less algebra and more physics, but it would be a poor student or researcher who could not learn a great deal from this book.

PETER D. KILLWORTH