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REVIEWS

Workbook on the Dispersion of Dense Gases. By R. E. BRITTER and J. MCQUAID. Health & Safety Executive, 1988. 128 pp. £35.

The hazards to the public associated with the industrial use of toxic or flammable dense (meaning denser than air) gases have been made all too clear by a number of recent disasters. Probably the best known of these recent disasters is the accidental release in 1984 of a large quantity of methyl isocyanate at the Union Carbide facility in Bhopal. The toxic dense cloud that resulted from that release moved through the town causing the death of at least 2500 people. The two features that dominate the description of dense-gas dispersion, and distinguish it from the dispersion of neutrally or positively buoyant gases, are the tendency of the gas to spread out along the ground as a density current and the reduced capacity, due to the stable density stratification at the cloud interface, of ambient turbulence to mix the gas with the surrounding air. These two features make toxic or flammable dense gas clouds especially hazardous because they tend to make the cloud spread over large areas and remain close to the ground in high concentrations.

Several countries now have regulations in force requiring industries that produce, store or transport hazardous dense gases to make a hazard assessment of their activities. This involves estimating the possibility and consequences of an accidental release into the atmosphere. Implicit in these requirements is a reasonable estimate of the shape and size of the area affected and of the maximum downrange distance from a typical accident at which the gas has become sufficiently dilute to make it no longer dangerous. The complex nature of density-driven flows in the atmosphere, the wide variety of types of gases in use, with their differing chemical and thermodynamic properties, and the many ways in which an accidental release can occur make estimating the consequences of a release a formidable task. Nevertheless, much progress has been made by a small research community in the last ten years or so in the understanding of the physics of dense gas dispersion and in the development of models to predict gas concentrations.

The stated purpose of this 'workbook' is to summarize the research community's current understanding of dense-gas dispersion in a form that can be readily applied by a non-specialist entrusted with making a hazard assessment. Such workbooks have been available for some time in the field of pollutant dispersion, which generally involves neutrally or positively buoyant gases, but no comparable reference has been available for dense gases due to the recent and rapid development of the field. This workbook was prepared under a contract with the UK Health & Safety Executive which is responsible for enforcing the UK regulations aimed at controlling major industrial accident hazards. Both authors are prominent and influential members of the dense-gas research community: R. E. Britter is a member of the Engineering Department at Cambridge University and editor of the Journal of Hazardous Materials and J. McQuaid is the Research Director at the UK Health & Safety Executive.

The first two chapters outline the problems which the workbook's methods are designed to solve, and describe the role of dense-gas dispersion within the larger framework of hazard assessment. The next three chapters develop the workbook's methods. In general, this is done by choosing the few most relevant variables out of the large number that fully describe a dense-gas release. Then dimensional analysis and the results of existing laboratory and field experiments are used to develop simple relationships for the size and shape of a contour of specified ground-level mean concentration. Probably the most important among these relationships is the expression for the downwind distance to a specified ground-level concentration. The goal is to be able to predict these quantities within 'a factor of two'. This is done initially, in chapter three, for two generic release types: the steady continuous release and the instantaneous release of a volume of gas with unit aspect ratio (both on flat terrain). Guidance is given on how to categorize a particular release (since most accidental releases are somewhere between these two release types) so that the most appropriate relationship or combination of relationships will be used in a practical application. Chapters four and five describe how these two archetypal cases can be modified to account for, among other things, atmospheric stability, source geometry, topography, the presence of buildings or other obstacles, and thermodynamic effects. In chapter six, the workbook methods are applied to several field tests and actual industrial accidents as examples of how to use the workbook in practice. The limitations of the workbook methods are described in the last chapter along with a discussion of some important problems in dense-gas dispersion that require further research.

Although the relationships for the size and shape of a specified concentration contour are fairly simple, choosing the appropriate relationship and correctly interpreting its results are not simple. These are complex problems that require a fairly thorough grounding in the fundamentals of dense-gas dispersion. The workbook does a fairly good job of making these points and chapter six is particularly instructive in showing the types of decisions and compromises that must be made in applying the methods to real problems.

On the whole the workbook achieves its purpose, although only further use of its methods will determine whether its predictions achieve the 'factor of two' accuracy in practice. To the non-specialist required to estimate the hazards associated with the accidental release of a dangerous heavy gas, this workbook is indispensable. Presently, there is nothing else available that provides such practical assistance in the estimation of the dispersion of dense gases. Although the workbook is intended primarily to provide practical assistance in making a hazard assessment, the general reader with an interest in fluid dynamics will find it to be a reasonable summary of the current understanding of dense-gas dispersion in the atmosphere, and the researcher will benefit from the discussion of important problems that still need to be solved.

J. W. ROTTMAN

Fluid Sciences and Materials Science in Space. Edited by H. U. WALTER. Springer-Verlag, 1987. 745 pp. DM 320.

My naive first reaction to the thought of experimental science in space was that, since the gravitational acceleration there would be zero, the physics would be simpler, possibly even boring. The introductory first chapter of this book quickly divested me of this notion, as it describes in some detail the true nature of the environment inside an earth-orbiting laboratory. To begin with there is a residual gravitational field (microgravity) which, though small, cannot be neglected and which, instead of being predictably constant in magnitude and direction, as on Earth, fluctuates as a result of many influences such as atmospheric drag, solar-radiation pressure and the internal machinery of the spacecraft itself. As one reads further into the book it becomes apparent that many physical effects, notably related to surface forces, that are negligible in the Earth-bound laboratory, are of equal importance with the micro-gravitational accelerations experienced in space. Suddenly, terrestrial gravity seems a reliable old friend and the orbiting laboratory presents a very complex, if not bewildering prospect.

However, initial fear of the unknown soon gives way to curiosity and excitement. As the rest of the book ably demonstrates, the space-bound laboratory opens up a challenging new world of scientific possibilities.

After the general introduction, the book is split into two parts: fluid sciences, covering dynamical effects, transport processes, chemistry and combustion; and materials science, mostly concerned with crystal growth and nucleation. It concludes with an overview of potential applications of the microgravity environment and, very importantly, a discussion of its limitations. The book carries the sub-title 'A European Perspective', signifying that the editor and authors are from Europe, but there is no specifically European bias apparent in the selection of material.

Although each section has been written by a different group of authors, the editor has done a good job of cross-referencing the articles. I began reading the sections that seemed most familiar to me and found I was directed to other areas of neighbouring interest. It would be presumptuous of me to give individual reviews of each section as there were several concerning fields about which I am not knowledgeable. I shall therefore confine my comments to a few sections and trust that these will give a flavour of the book as a whole.

Chapter III entitled simply 'Fluid Dynamics' is the longest in the book and, for me, the least satisfactory. To be fair, my dissatisfaction may stem in part from my greater familiarity with this topic than with many of the others, since I found it quite unstimulating. The chapter introduces basic equations and elementary solutions for a whole gamut of different fluid-mechanical situations. It could therefore serve as a background for the rest of the book, much of which employs fluid mechanics to some degree. However, I didn't feel that the material was very well presented, even when considered as a reference text. A further criticism in view of the subject of the book is that the article is extremely Earth-bound. Most of the flows considered are driven by gravity e.g. Rayleigh–Bénard convection, surface gravity waves, gravity-driven flow down a slope. There is a catalogue of some fluid-mechanical experiments performed in microgravity but no real details are given.

By contrast, I found Chapter II on capillarity very enjoyable. The topic is nicely introduced and basic physics is clearly explained and motivated. The authors are careful to point out deficiencies in current theories of interfacial phenomena and describe how experiments conducted in microgravity might be used to test different hypotheses. A short section on the results of previous experiments in microgravity include some fascinating photographs and the article is rounded off with a discussion of future prospects and applications.

This pattern of a basic introduction for the layman, a description of current research interests, results of experiments conducted in microgravity compared with Earth-bound studies and a prognosis of future potential is adopted by most of the articles.

Research aimed more directly towards industrial processes occupies the second half of the book. Much of it is still concerned with fluid-mechanical phenomena since most of the applications involve the formation of solid materials from a liquid or vapour phase. For example, the first of these articles, Chapter X, discusses crystal growth from melts; a topic of great importance to the semiconductor industry. After discussing the limitations of terrestrially based technologies, the authors describe some of the fundamental physical processes involved including Marangoni convection – the flow induced by inhomogeneities in the surface tension at fluid interfaces caused by variations in temperature, for example.

Crystal growth from a vapour phase is discussed in Chapter XI. The authors of this article caution that the advantages of materials processing in space were somewhat oversold to the public before any substantial proofs had been obtained but concede that crystals grown in space do generally have much higher perfection than those grown on Earth.

An extremely fascinating area of current research is the study of the formation of patterns from initially homogeneous systems. This book contains a number of examples, many beautifully illustrated, from fundamental work with simple chemical reactions (Chapter VIII), through the growth of dendrites during the solidification of alloys (Chapter XIV), to the more complex patterns encountered with biological crystals (Chapter VIII). The bifurcations leading to such patterns may be more easily studied in space where surface phenomena have a dominant influence on the dynamics of a physical system.

I am aware that I have not commented on a large number of the articles in this book and that in reading it I have been guilty of satisfying my own personal interests. My guess is that most people picking up this book will do the same. There is much in it to enjoy, inspire or to challenge. I would encourage anyone working in the fluids sciences or materials sciences to browse through it and suspect that many will find something in it to make them read further.

M. Grae Worster

Mathematical Problems of Statistical Hydromechanics. By M. J. Vishik and A. V. Fursikov. Kluwer, 1988. 576 pp. $149 or £90.

The fundamental objective of Statistical Fluid Mechanics is the study of the probability distribution of the random fields describing the fluid. In the phase space H of the flow the solution of the deterministic equations of motion (incompressible Navier–Stokes equations in the present case) is a map $S(t)$ which assigns to the initial datum u_0 the value $S(t)u_0 = u(t)$ representing the solution at time t. If the initial datum is a random field whose distribution is the measure μ (defined in the phase space H) then the spatial statistical solution corresponding to it is the measure μ_t defined by $\mu_t(\omega) = \mu(S(t)^{-1}(\omega))$. A more general concept is that of a space–time statistical solution P which can be described as follows. Consider a space of paths in H, $\mathscr{P}$. A space–time statistical solution is a probability measure in $\mathscr{P}$ which is supported on paths which are solutions of the deterministic equations and which satisfies $P(\Omega) = \mu(\omega)$, where Ω is the set of those paths that start in ω. In principle one can obtain spatial statistical solutions from space–time solutions by evaluation at time t, that is, by setting $\mu_t(\omega) = P(\Omega_t)$, where Ω_t are those paths that pass through ω at time t. Because the phase space is infinite dimensional the existence and uniqueness of statistical solutions is not a trivial matter. In a seminal paper, Hopf (1952) deduced the equation satisfied by the characteristic functional

$$\chi(t, v) = \int \exp(i\langle v, u\rangle)\, \mathrm{d}\mu_t(u).$$

Twenty years later Foias (1972) formulated an analogue of the classical Liouville equation for μ_t and proved using this formulation that spatial statistical solutions of the two- or three-dimensional Navier–Stokes equations exist and are unique in the two-dimensional case. The solution given by Foias provided, for the first time, a solution to the Hopf equation.

In the book under review the authors prove the existence of space–time statistical solutions for both two- and three-dimensional Navier–Stokes equations as limit points of space–time statistical solutions of Galerkin approximations. The fact that μ determines uniquely P is proved for two-dimensional Navier–Stokes equations. The Hopf equation and the Foias equation are approached using the space–time statistical solutions. Special attention is paid to the infinite chain of moment equations (the Friedman–Keller equations) for both low and large Reynolds numbers. Spatially homogeneous space–time statistical solutions are also studied and the inviscid limit is obtained in two dimensions. The authors construct statistical solutions for Navier–Stokes equations driven by white noise. Most of the results are original and many of them appear for the first time in English. Although not easy to read, mainly because of the poor translation and editing, the book is clearly written and the authors are among the most respected experts in the field.

The work is not intended to be a comprehensive treatise on the subject; important results such as the recent connection between self-similar families of homogeneous statistical solutions and the Kolmogorov spectrum (Foias, Manley & Temam 1987) are not included. It is, to my knowledge, the first book in English which presents the rigorous mathematical results of Statistical Fluid Mechanics. This is an important monograph, covering vast material.

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P. Constantin

Dynamics of Polymer Liquids. Vol. 1: Fluid Mechanics (2nd Edn.) By R. B. Bird, R. C. Armstrong and O. Hassager. 649 pp. £65; **Vol. 2: Kinetic Theory** (2nd Edn.). By R. B. Bird, C. F. Curtiss, R. C. Armstrong and O. Hassager. 437 pp. £57.50. Wiley, 1987.

The Wisconsin group produced the first edition of their text book on polymeric fluids a decade ago, and in this new edition they have added to and have substantially rewritten both volumes. The work is still intended as an introduction to the subject and its style of presentation is unchanged: no effort has been spared to ensure that the text is clear, detailed, thorough and self-contained. Indeed, the endeavour to make the new edition complete perhaps goes too far in some instances – one does not expect to find an eight-page discussion of the calculus of variations in a book about polymers. There are numerous examples, worked exercises, appendices on tensor manipulation and coordinate systems, and a host of helpful graphs and summary tables of results and formulae.

Volume 1 is concerned with flow behaviour of polymeric solutions and melts. The chapters from the first edition concerning 'standard' non-Newtonian fluid models (the Newtonian fluid itself, linear viscoelastic and second-order fluids, and the 'generalised Newtonian fluid' having a flow-rate-dependent viscosity) have been added to, but are otherwise intact. Additionally the excellent chapters on material functions and flow phenomena in polymeric fluids remain. But the sections from the first edition concerning corotational models have been deleted in favour of largely new material on constitutive equations of differential and integral types that currently enjoy greater popularity with research workers. An excellent service is done for readers by bringing together data on suitable model parameters and also by showing some computed solutions in complex geometries. Finally a new section on rheometry has been added. These changes to the book have made it more accessible and more topical. In the opinion of the reviewer the book provides at a graduate student level the best introduction to the subject presently available.

Volume 2 is concerned with the kinetic theory of polymers and adopts the approach of the chemical physicist. It differs from volume 1 in having in my view more the character of a research monograph than that of a text book. Useful introductory material has been added to the new edition in providing a physical description of polymer molecules and models, but large parts of the text consists of unwieldy manipulations of complex expressions that yield results too complex for the flow calculations discussed in volume 1. Sections have also been added to incorporate the recent work of Doi & Edwards on reptation, but for this reader the simplicity and clarity of Doi & Edwards' physical conception is lost in this formalised treatment. In his review of the first edition (*J. Fluid Mech.* **86**, 1978, 204) J. R. A. Pearson noted that this presentation makes no contact with the suspension work of Einstein, Batchelor and others; sadly that omission has not been repaired in the new edition.

Professor Bird and his colleagues have done us a great service in bringing their work up to date. I dare to hope that there will in the fullness of time be a third edition (preferably in which the idiosyncratic sign convection for the stress tensor has been abandoned!) produced with the same care and attention to detail as the first and second.

J. M. Rallison