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REVIEW

Turbulent Diffusion in the Environment. By G. T. Csanady. Geophysics and Astrophysics Monographs. Reidel, 1973. 248 pp. Df1270.

One might have thought that with universities all over the world providing ever more lecture courses on environmental problems there would have been a spate of books on the fluid-mechanical aspects. In fact very few have been written and therefore this book by Csanady is to be welcomed. It has evolved from a lecture course on turbulent diffusion to graduate students specializing in 'environmental fluid mechanics'. It is not a textbook of turbulent diffusion containing all the necessary fundamental theory and the basic experimental results; such a book has yet to be written. However it does contain some of these ingredients, as well as being an account of those fluid-mechanical meteorological and oceanographic processes and a review of those practical formulae that ought to be familiar to engineers working on environmental problems. There are parts of the book which read less like a textbook but more like a monograph about the wide range of particular problems of turbulent diffusion which the author himself has investigated.

The first chapter is a useful introduction to the physics of molecular diffusion and the equation of convective molecular diffusion. It is convenient for students that most of the common solutions to this equation are given here with diagrams. These need to be understood before a student can proceed to the problem of turbulent diffusion.

The second chapter begins with a unified account of the statistical theory of turbulent diffusion and Brownian motion. The treatment follows that of Batchelor for the relation between concentration and probability density function for the position of a 'marked' particle, and then Taylor's (1922) results for one-dimensional diffusion are deduced. Definitions of a stationary process and the autocorrelation function are imprecise and, regrettably, the author does not refer the student to more precise analyses elsewhere, such as the recent book of Monin & Yaglom. In the rest of the chapter the theory of Brownian motion is developed and illustrated with applications of aerosol deposition on surfaces.

Chapter 3 begins with a non-mathematical account a page or two long of the fundamental concepts of homogeneous turbulence, before plunging into explanations of various methods of field measurement of concentration and dosage and the reasons why a statistical approach to environmental diffusion is necessary. Then, with the briefest mention of molecular processes in turbulent diffusion, Eulerian and Lagrangian statistics are introduced entirely verbally. Perhaps this informal approach to the theory of turbulent diffusion maintains the interest of the students, but I find it confusing and would be surprised if students did not also. Either the more abstract ideas are worth explaining with ample diagrams and equations or they should be omitted as they are in Scorer's book on *Air Pollution*. The next part of chapter 3 is a development from the asymptotic form of G. I. Taylor's result for the mean-square displacement of a particle to a justification of the use of the eddy diffusivity K in diffusion calculations. Despite eddy diffusivity having been labelled by G. I. Taylor as an 'illogical conception', it still has its uses both in explaining many phenomena in turbulent diffusion and in making practical calculations. Csanady discusses its limitations but concludes that "many useful and realistic theoretical results may be derived by means of the concept of an eddy diffusivity". This echoes Tennekes & Lumley's recent book, *A First Course in Turbulence*, where it is stated on p. 226 that eddy diffusivity "is a useful, though rather crude, approximation in many cases of practical interest". Throughout Csanady's book eddy diffusivity is used to examine diffusion problems and with great effect. There follows an account of laboratory diffusion experiments, described as confirming Taylor's theory, which is misleading because the role of molecular diffusion is not explained. In the experiments quoted (done in 1944) molecular diffusion is not important, but a similar curve of plume thickness against distance can also be found when molecular diffusion occurs, so that the form of the curve does not confirm the theory unless it is shown that the effects of molecular diffusion are negligible. It is a pity that no description is given of the recent experiments of Snyder & Lumley (*J. Fluid Mech.* **48** (1971), 41), in which Lagrangian correlations and the mean-square displacement of particles were measured. These experiments are significantly better confirmations of Taylor's theory than those quoted. They should also have been referred to when mentioning the hypothesis that the curves of Eulerian and Lagrangian autocorrelations have similar shapes, because these recent experiments provide a stronger confirmation of this practically useful hypothesis than any earlier ones.

Chapter 4 contains some good examples of lake and oceanic pollution to illustrate the ideas of relative diffusion. The statistical theory of two-point diffusion is developed fully and explained well. This leads into the uses of eddy diffusivity and the diffusion equation for calculating concentrations in clouds of pollution.

Chapter 5 on dispersion in shear flow begins with a few points about the wind in the planetary boundary layer. A clear account is given of the similarity theory of diffusion from a line source near the ground and its development by the use of eddy diffusivity. Experimental results are given but again the experiments are not adequately described for the reader to judge whether they do or do not exactly test the theory. An interesting point is made that there is little little difference between calculations of concentration downwind of an elevated source where the eddy diffusivity K varies with height and where it does not. The physical mechanism whereby a shear flow augments dispersion is explained solely in terms of K theory, whereas there is a simple and rigorous statistical argument due to Corrsin and which was described in Tennekes & Lumley's textbook.

Chapter 6 on the "effects of density differences on environmental diffusion" covers a subject which merits a book on its own, and therefore the selection of topics must be somewhat idiosyncratic. The turbulent energy equation is derived, the Richardson number is introduced and the relevant physical ideas are described quite adequately. But there is a misleading remark that in stable sheets of fluid where sharp gradients occur diffusion is entirely molecular. The recent book by J. S. Turner on *Buoyancy Effects in Fluids* shows that this is not always true as for example when waves occur on interfaces. Diffusion 'floors and ceilings' are analysed by K theory and related to the serious pollution phenomena caused by inversion 'lids' in hilly terrain. Details are given of the author's theory of turbulent diffusion in a stratified flow without any reference to other recent theories of turbulence in stratified flow. The line thermal is introduced because it resembles a buoyant plume bent over by a transverse wind. The integral invariants and similarity results for a line thermal are deduced with unnecessary length and complication from the differential equations. Then the various phases of the development of a chimney plume in a turbulent wind are described in terms of the relevant dimensionless groups. The analysis could have been simpler because the development of the behaviour of a plume from that like a jet near the source to that like a line thermal downwind can be analysed quite straightforwardly using the entrainment concept originally developed by Morton, Taylor & Turner (Hoult, Fay & Fornley, *J. Air Pollut. Control Ass.* **19** (1969), 585). Csanady does discuss entrainment, but puts the word in inverted commas and tends to play this concept down, whereas this reviewer believes that it should be presented as a mechanism as important as turbulent diffusion for dispersing high concentrations of pollutant discharged into the environment, e.g. car exhausts, power station outlets or buoyant chimney plumes. Csanady presents some of his recent theories on the effect of stratification on plume rise and ends the chapter with a useful review of the effect of plume rise on ground-level concentrations downwind of a chimney.

The final chapter is a useful account of what little is known about the important practical problem of fluctuations N' in concentration. Gifford's analysis is given for N' produced by a meandering plume. Only a passing mention is given of the spectral analysis of $N(\mathbf{x}, t)$, developed by Batchelor & Townsend, but a semi-empirical theory of N'^2 is developed for fluctuations in plumes and compared with experiments in some detail. As Csanady points out, more theory and detailed experiments are needed to enable predictions to be made of fluctuations in concentration.

There are three irritating omissions from this book, namely a unified bibliography at the end of the book, titles of cited articles, and an index. Despite this and the other criticisms I have made, I can and do recommend this book to students and to anyone researching into problems of turbulent diffusion, but they should be aware of the inadequate references and the occasionally misleading bias towards the author's own interests and theories.

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