PERGAMON

International Journal of Multiphase Flow 27 (2001) 947–948

International Journal of Multiphase Flow

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Book review

***Principles of gas–solid flows* by L.-S. Fan and C. Zhu, Cambridge University Press, 1998; p. 557**

This is a well-written book on gas–solid flows written from the particle technology perspective. It provides a well-illustrated, integrated, and authoritative account of the basic principles that include the essential physics underlying gas–solid flows. It also contains excellent classical and state-of-the-art material on applications of gas–solid flow systems.

The book introduces the complex subject of gas–solid flows using an approach, which encompasses thorough mathematical analyses. The broad range of concepts is described succinctly yet clearly. Carefully selected references are given. The book covers quite a few interdisciplinary topics useful to readers with chemical, mechanical, or related engineering and applied science backgrounds

The text contains two parts, basic relationships and system characteristics, each comprising of six chapters. Part I offers a systematic treatment and thorough derivation of theories with clear illustrations and working examples. The first six chapters cover a very broad spectrum of fundamentals, encompassing particle sizing, collision mechanics, interfacial interactions via momentum, energy, charge and mass transfer, and multi-phase flow modeling and intrinsic phenomena. Chapter 1 introduces basic definitions of various equivalent diameters of a non-spherical particle and the corresponding sizing methods. Typical size distributions, size averaging methods, and particle properties are also discussed in detail. Chapter 2 gives a thorough account of collisions of elastic spheres, which is also applicable to the case of particle–wall collisions. A detailed introduction to Hertzian contact theory is presented, from which analytical expressions of important and transient collision parameters such as collision area, contact time, force or surface stress, and elastic deformation are rigorously derived. Theories on collisions of frictional, twisting, and inelastic spheres are also included. The basic modes of momentum, charge, heat and mass transfer due to gas–particle interactions, particle–particle interactions, and external fields are described in Chapters 3 and 4. Hydrodynamic forces of a single particle with a relative motion of translation, rotation, or acceleration in an unbounded uniform flow in the creeping flow regime are derived. Highlights of Chapter 4 include basic mechanisms of charge generation, charge transfer by particle collision, thermal radiation of dense particle phase, and heat conduction in collisions of elastic solids. Chapter 5 introduces four modeling approaches for gas–solid flows, namely, continuum modeling, trajectory modeling, kinetic theory modeling for collision-dominated dense suspension, and the Ergun equation for flow through a fixed bed. The basic concepts of the kinetic theory of gas and the k–ε turbulence model are discussed as a preamble to the comprehensive introduction to the modeling of gas–solid flows. Since most continuum modeling of multi-phase flows is volume average based, the general volume-averaged equations of multi-phase flows are derived from constitutive relations of intrinsic phases using the volume-averaging theorems. Trajectory modeling covers both deterministic and stochastic approaches. While trajectory modeling is typically applied to flows with very dilute suspensions, the kinetic theory modeling is aimed at another extreme,

PII: S0301-9322(00)00072-0

namely, very dense suspensions where the flow motions are dominated by particle collisions, and so a detailed introduction to the kinetic theory approach is presented. In the last part of Chapter 5, Darcy's law and Ergun's equations are introduced for flow through a fixed porous medium, addressing the limiting cases of dense particle suspensions, such as minimum fluidization. Some intrinsic phenomena and common concerns in gas–solid flows, including erosion and attrition, acoustic wave and shock wave propagation, thermodynamics of gas–solid mixtures, flow instability, and turbulence modulation are covered in Chapter 6.

Selected industrial systems and processes are introduced in Part II. These selected systems represent the important engineering applications in the field of gas–solid flows. Chapter 7 discusses gas–solid separations including basic separation methods extensively used in the separation industry, e.g. cyclones, electrostatic precipitators, filters, gravitational settlers and wet scrubbers. Calculation methods for separation efficiency and pressure drop are provided. Chapter 8 treats the problem of hopper and standpipe flows with an emphasis on powder mechanics and flowability of powders. Pressure distribution and leakage flow in standpipe flow systems are also discussed in detail. Chapter 9 focuses on dense-phase fluidization and introduces a complete account of the basic concepts of gas–solid fluidization, including Geldart classification of fluidized particles, fluidization and operating regimes of a fluidized bed, and dynamic properties of bubbles, clouds, and wakes. Chapter 10 addresses the fundamentals of circulating fluidized beds and introduces some models for regime transition, solids holdup and flow structure. Chapter 11 deals with the pneumatic transport of solids in pipelines. Interesting and challenging phenomena such as drag reduction; gas–solid flows in bends, and critical transport velocity are discussed and analyzed theoretically. The last chapter of the book is devoted to describing the transport phenomena of heat and mass transfer in fluidized beds. Phenomenological models for estimation of heat and mass transfer coefficients are included.

The authors provide a well-organized linkage of fundamentals of gas–solid flows from rather diversified disciplines such as collision mechanics, kinetic theory, turbulence modeling and phase modulation, charge generation and transfer, and powder mechanics, providing an integrated knowledge base necessary for understanding gas–solid flows. The thorough derivation of working equations provides a clear physical interpretation and hence shows the limitations of the mathematical models. A complete account of up-to-date modeling techniques of gas–solid flows is introduced in increasing order of complexity. A solution manual is also available from the publisher.

To sum up, it is appropriate to cite the late Professor S.L. Soo's unsubmitted, written comments on this book dated January 12, 1998: "The volume is a thorough and rigorous treatment of the subject over and beyond any previous book on related topics. My sincere congratulations to the authors on such an important contribution to education and research on this subject." It is recommended as a textbook for teaching graduate students and advanced undergraduate students who have good mathematical backgrounds, including vector analysis and partial differential equations. Because of its depth, breadth, and clarity, the book would also be valuable for practitioners and research scientists working in gas solid flow area as a primary reference source.

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