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Book Reviews

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Combustion of Two-Phase Reactive Media

L. P. Yarin and G. Hetsroni, Springer-Verlag, New York, 2004, 558 pp., $189

Two-phase combustion is of great interest in practical engineering applications related to heat exchange, power generation, and material processing. The description of such phenomena is based on the ordinary conservation laws, written for each phase and supplemented by source terms arising from the interchange of mass, momentum, and energy between the phases. In reactive media, the complexities are compounded by chemical kinetics, which can be daunting even for the simplest of combustibles. Although books dealing with two-phase flows have been published in the past few decades, no comprehensive monograph devoted to two-phase combustion has been published. The lack of such a monograph led the authors to attempt to fill the gap with this publication. In a book designed primarily for professional scientists and engineers, the authors adopt an approach that, in their words, combines the methods of the classical theory of combustion with the methods of the theory of multiphase flows in dealing with combustion problems in two-phase reactive media.

The book consists of an interesting collection of topics associated primarily with heat and mass transfer. When combustion is incorporated into the discussion, it is introduced in its simplest form. The text is approximately 550 pages in length and is divided into three parts. The first part, which covers nearly 300 pages, deals with a single particle. It consists of six chapters. Chapter 1 is concerned with the drag on solid particles, drops, and bubbles. Results associated with various factors that affect the drag coefficient, including vaporization and combustion, are discussed. In chapter 2, the basic correlations used to calculate the heat and mass transfer coefficients are presented along with results on droplet vaporization. Chapter 3 addresses questions associated with particle ignition, ignition and combustion of coal, and metallic particle and droplet combustion. Particle interaction and particle-turbulence interaction are discussed, respectively, in chapters 5 and 6. The second part of the book, which covers nearly 150 pages, deals with the propagation of combustion waves. It consists of four chapters. Starting with waves in homogeneous media addressed in chapter 6, the discussion evolves into wave propagation in bubble media in chapter 7 and filtration combustion in chapter 8. The last chapter, chapter 9, is concerned with turbulent heterogeneous flames. The third part of the book, which covers 70 pages and consists of two chapters, deals with two specific technological problems characteristic of high-temperature combustion reactors: the gas–liquid reactor model is discussed in chapter 10 and the displacement reactor in chapter 11.

Although it has been suggested that the book can be used for a graduate-level course, the style of presentation limits its value as a graduate text. In neither the first part, which deals with single particles, nor the second part, where the real discussion of two-phase flow starts, does one find a unified mathematical formulation. For each problem, the governing equations and boundary conditions are generally stated with little or no explanation. Detailed solution techniques are usually omitted, with few exceptions involving the relatively simpler mathematical development. The combustion-related material does not properly reflect the recent advances in the field, as further elaborated next. Missing, in particular, is a comprehensive discussion of the various possible approaches used for the treatment of two-phase reacting flows; e.g., a continuum formulation, discrete-particle, or probabilistic approach. Nevertheless, given the large number of citations, this book may serve as a useful reference for graduate students who wish to start working in the field.

Readers will likely notice a lack of symmetry in the treatment of various topics. Although some topics, such as the last two chapters that rely heavily on publications of the lead author, are presented in an elaborate manner with substantial details, others are presented as an encyclopedic review. The first two chapters dealing with the drag and heat/mass transfer coefficients of single particles are such; they contain a compilation of results and formulas obtained by various investigators, covering a wide range of conditions. Although practically useful, the absence of a discussion that clarifies the limitations of the models used in producing a given expression hinders the significance of the presentation, particularly to a reader with no familiarity with the subject matter. For example, several formulas are listed on pages 5 and 6 as representing consecutive approximations for the drag on a solid particle in a viscous fluid. It would have been valuable to elucidate in this context that Stokes's approximation is not valid in the far field of the particle, whereas Oseen's theory and its extension to higher orders by Goldstein, which are valid in the far field, do not satisfy the proper boundary conditions at the surface of the particle. It is the resolution of these difficulties by means of matched asymptotic expansions that led Proudman and Pearson to expression (1.27), which, although derived for $Re \ll 1$, is found valid for Reynolds numbers up to $Re \approx 4$. It should be noted that the formula (1.26) associated with Goldstein contains a misprint; the term corresponding to $\mathcal{O}(Re^2)$ in this expression should be negative.

One way in which the monograph falls short is that it does not provide a true state of the art of the combustion-related material. The discussion does not reflect the important advancements in combustion theory made over the past 30 years. One of the most powerful tools in dealing with the highly nonlinear reaction rates encountered in combustion problems is activation energy asymptotics. Although the physical consequences of this limit were well recognized in the earlier work of Zel'dovich and Frank Kamenetskii, its systematic implementation in the Western literature since 1970 led to significant achievements and a high level of conceptual coherence. Results include explicit expressions for the propagation velocity of combustion waves, conditions identifying limits of flame propagation, criteria for ignition of particles and fuel drops, explicit solutions for droplet combustion, combustion of coke and metallic particles, analysis of diffusion flames accounting for finite rate chemistry, criteria for flame extinction, and more. Yet, apart from occasional references to recent work, the text is mostly based on outdated material. The ignition of a single particle is presented in Sec. 1.3.1 within the framework of a lumped-capacitance heat transfer model, which is analyzed using a Semenov-type approach. Droplet combustion is discussed (Sec. 1.3.6) using the Schvab–Zel'dovich formulation, with no reference to the effects of finite-rate chemistry and nonunity Lewis numbers. Criteria for extinction of diffusion flames (p. 153) and for the limits of propagation of combustion wave in homogeneous media (p. 306) are based on a heuristic phenomenological approach. The introductory comments on stability on p. 399 ignore the abundant literature on flame stability and the associated experimental and analytical determination of Markstein lengths.

Overall, the monograph provides a useful entry into the challenges presented by two-phase combustion and may serve as a useful reference for the more practical aeronautical, mechanical, and chemical engineers with a research bent.

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