Preface

This book is intended to provide an overview of the processes that occur in atomization and spray systems. It covers both the classical, theoretical concepts of atomization and more recent developments. The book is organized into four parts. Part I deals with the basic elements of a liquid that form a spray. These are liquid jets, sheets, and drops. Part II deals with theories of atomization and sprays. Part III discusses spray nozzles and their behavior. Part IV concludes with spray applications.

The atomization process is very complex, involving highly turbulent and convoluted interfaces as well as breakup and coalescence of liquid masses. However, the models currently used to describe the atomization process are based on simple laminar instability theories. In many spray nozzles, a liquid is forced through an orifice. These types of nozzles form a liquid jet at low injection pressures. Therefore, the instability theory of liquid jets is used as a first estimate of the droplets that may be formed by these nozzles. In many other spray nozzles, a liquid sheet is formed prior to atomization. Therefore, the instability theory of a liquid sheet is used for these prefilming nozzles. Part I introduces the instability theories for these two configurations. Linear and nonlinear instabilities of a free liquid jet moving in air and subject to small perturbations are discussed in Chap. 1. These theories intend to provide the growth rate of a disturbance wave. The growth rate of the fastest growing disturbance is later used in the atomization theories to obtain a droplet size due to the breakup of a jet. Therefore, the linear theories provide an estimate of the main droplet size emerging from capillary breakup. Formation of satellite droplets and other effects such as thermocapillarity or swirl are also discussed in this chapter. Chapter 2 is devoted to jet bending and Chap. 3 discusses the linear and nonlinear instability theories for a liquid sheet. Instability of a liquid sheet results in the formation of cylindrical liquid ligaments, which have the same fate as liquid jets. Therefore, liquid sheets and liquid jets in combination are used to describe the atomization process in nozzles that form a film or sheet prior to atomization (prefilming atomizers). The spray itself is made of millions of droplets that flow inside a gas. The interaction of a liquid drop with a coflowing gas, including oscillation, deformation, and breakup, is discussed in Chaps. 4–6. Drops may also collide with each other (Chap. 7) or with the walls of the system (Chap. 8).

Part II utilizes the basic instability theories discussed in Part I to develop models for the atomization and spray systems. Chapters 9–11provide the current atomization theories used in spray systems to predict a droplet size. The most commonly used atomization models, namely, the Taylor analogy breakup (TAB) model, the enhanced-TAB (E-TAB) model, and the WAVE model, and variations and improvements of these models are discussed in Chap. 9; the concept of flash atomization and supercritical injection are introduced in Chaps. 10 and 11, respectively. Chapters 12–16 introduce spray theories dealing with spray evaporation, combustion, and freezing. Spray evaporation is modeled based on evaporation of individual droplets, which is discussed in Chap. 12, by means of the conservation equations for mass, species, and energy of the liquid and gas phases. The results of single droplet evaporation are simplified and used for heat and mass transfer for forced and non-forced convection through Nusselt and Sherwood numbers. Reacting sprays are discussed in Chap. 13, introducing chemical kinetics, ignition processes, and mixing-controlled, flamelet, and PDF combustion models. A brief discussion on the pollutant and particulate models is provided in this chapter as well. Some other important spray issues such as spray group combustion and sprays in non-continuum regimes are also discussed in Part II. Flame propagation modes between neighboring droplets and macroscopic flame propagation modes in spray elements, and the excitation mechanism of group combustion (diffusion flame enclosing droplets) is described in Chap. 14. The evaporation process is altered significantly at low pressures. This is discussed in Chap. 15 for flows in which the mean free path of the evaporated molecules is large compared with the droplet radius. This chapter discusses the kinetic theory of gases as applied to molecules having the Maxwell–Boltzmann distribution of molecular velocities. The concept of the Knudsen regime is introduced to develop a transport equation for the molecules at the droplet interface. Droplet freezing and solidification is considered in Chap. 16 with emphasis on a four-stage model for solidification. Because of the recent enhancement in computational capabilities, direct numerical modeling of the atomization process has become more feasible. The models used for tracking deforming and breaking interfaces to simulate the atomization process are discussed in Chaps. 17 and 18. The spray models that track droplets are introduced in Chaps. 19 and 20. The turbulence models used in spray modeling, including Reynolds-averaged Navier–Stokes (RANS) and large eddy simulation (LES) modeling, are introduced in Chap. 19; the non-continuum-based computational techniques, for example, the lattice Boltzmann method (LBM), are introduced in Chap. 20. Chapters 21 and 22 introduce special topics of spray wall impact and spray-spray impingements and interaction. Chapter 22, in particular, addresses questions like, "is the use of multiple sprays more effective than the use of a single spray, or is it possibly detrimental? And, if the latter is true, can the situation be ameliorated by manipulation of the physics through geometric and other factors that relate to the sprays?"

The main objective of atomization and spray systems is to generate a spray with a desired droplet size and velocity distribution. Part III deals directly with spray nozzles. This part starts with Chap. 23, which discusses the concept of droplet size distribution. Chapter 24 provides an overview of various spray nozzles and their droplet size distributions. A series of size correlations are included at the end of Chap. 24 for ease of use. Various correlations are compiled from different sources. Chapters 25–33 provide more detailed discussions on different types of nozzles. In particular, plain orifice atomizers, pintle injectors, jet-in-crossflow atomizers, impinging jet atomizers, splash plate nozzles, electrosprays, and several other atomizers are discussed in Part III.

Part IV is devoted to spray applications. This part is by no means exhaustive of all applications and is kept limited to applications in various engines, melt atomization, and several other specific applications. In engine applications, port fuel injection (PFI), throttle-body injection (TBI), direct injection (DI), and diesel injection are discussed in Chap. 34. For gas turbine engines, the modeling methodologies, including LES, of reacting flows in realistic combustor configurations are discussed in Chap. 35. Another spray application extensively discussed in this book is melt atomization and powder generation. Melt atomization, which is the dominant method used commercially to produce metal and alloy powders, is considered in Chap. 36. Mechanisms of melt breakup and atomization, powder morphology, droplet dynamics, and so on are considered. In addition, fundamentals of spray drying, spray pyrolysis, spray freeze drying, low pressure spray pyrolysis, flame spray pyrolysis, and emulsion combustion method are described in Chaps. 37–40. Sprays have an important application in drug delivery to the lungs. Chapter 41 discusses the pharmaceutical aerosol sprays. The book is closed with fire sprinklers discussed in Chap. 42.

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