chamber, the solvent component of the feed stream, which can include water, alcohol, or other organic solvents, is rapidly removed by the continuous flow of a heated gas (usually air or nitrogen). The dried, solid residual particles are collected in a collection device. Spray-drying is well suited to the preparation of biopharmaceuticals despite the heat of the drying gas. Because of the rapid conversion of the solvent component of the feed stream to the gaseous state, the temperature experienced by the remaining constituents of the feed stream is much lower than the inlet temperature of the device, extending the range of tolerable processing temperatures available for sensitive biologics [5]. The process is rapid, energy efficient, and does not require the pretreatment of the feed stream prior to spraying, in contrast with, for example, lyophilization that requires freezing the sample prior to drying.

Several types of atomizers are used in the spray-drying industry including spinning disk atomizers, one-fluid spray nozzles (also referred to as pressure or hydraulic nozzles), two-fluid spray nozzles, ultrasonic nozzles, and piezoelectric nozzles. Each type of atomizer has been utilized in spray-drying of pharmaceutical products, each coupled with their own advantages and disadvantages. The core of a spinning disk atomizer, as its name suggests, is a rotating disk which, when rotating at high speeds, causes the liquid feed stream to impinge on the disk surface and atomize into small droplets. Changing the speed of the disk, the number of grooves, and the shape of the grooves on the disk affects the pattern and size of the atomized spray. The process may be used for fairly viscous samples, and produces a relatively uniform particle size. However, since the droplets are expelled in a horizontal direction, a wide drying chamber is needed for this atomizer. A one-fluid spray nozzle utilizes the shear of the fluid passing through the nozzle's small orifice to atomize the sample, accommodating low-viscosity samples and producing fairly uniform droplet sizes. However, this type of nozzle cannot be used for high-viscosity feed streams, has a tendency to clog, and is subject to variations in the atomization of the feed because the shear is directly dependent on the passage of the fluid through the nozzle. A two-fluid nozzle attempts to alleviate some of these problems by using a stream of gas to shear the feed stream at the tip of the nozzle. The added shear imposed by the gas stream enables these nozzles to spray higher viscosity fluids than those permissible with one-fluid nozzles. The two-fluid nozzle produces a more uniform spray pattern but with some variability in droplet size [6]. Ultrasonic nozzles apply ultrasonic vibration to the nozzle tip to atomize the feed stream. These nozzles produce more uniform droplets, are less likely to clog, have less overspray, and can produce a smaller overall droplet size than conventional spray nozzles. The feed rate tends to be lower for ultrasonic nozzles than for the other nozzle types.

Many different modifications of these basic types of nozzles exist [7, 8]. For instance, researchers have developed three- and four-fluid nozzles that have multiple feed streams in addition to the gas stream [9, 10]. Büchi Labortechnik (Flawil, Switzerland) has developed a piezoelectric spray nozzle that vibrates a perforated steel disk to atomize the feed stream [11]. While the feed rate is relatively low compared with other nozzles, this atomizer can produce submicron particles.

The design of the drying chamber depends on the choice of atomizer and the desired drying characteristics and can be divided into two major types: tall/narrow