Design and Operation of a Spray Dryer for the Manufacture of Hollow Micro-particles

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Extended Abstract

1. Introduction

Spray drying is the process of transforming a liquid into a dry, particulate solid by atomizing the liquid and bringing the liquid in contact with a hot gas. Such a process may be achieved in a spray drying chamber. Spray dryers are extensively used in many industries such as the food industry to dry the liquid feed when close control over the product size distribution is needed. Spray dryers also have been used to manufacture hollow or solid micro-particles for different applications such as the manufacture of light-weight composites, etc. [1]. In a spray drying operation, there are three main phenomena that need to be understood completely. They are: 1) atomization of the liquid feed, 2) drying of the droplets once they are formed, and 3) motion of the droplet to model the spray drying process. Due to the difficulty in modeling all these processes, the design of spray dryers has remained largely an empirical process.

In this work, a design methodology for spray dryer design, based on modeling the heat and mass transfer inside the chamber and particle-tracking is presented [2]. Since the chamber is designed to manufacture hollow polymeric particles, the design model is coupled with a single droplet model that describes solvent and solute concentrations and temperature within a single droplet. The design methodology is demonstrated on a design that uses a polymeric solution with water as the solvent and air as the drying gas. The design is validated against an existing laboratory-scale spray dryer chamber. Using the model of the spray dryer system, feasible operating conditions for the chamber are identified as a function of the amount of solvent that remains in the particle. The design parameters identified are, the length and radius of the chamber, the heating and drying gas flow rate requirements.

2. Design Methodology

A suitable atomizer is chosen depending on the size distribution of particles that is required and the production rate or throughput. For example, if a large throughput is required, a centrifugal pressure nozzle may be used. If tight regulation on the particle size is not required, a rotary disc atomizer might be used. This work explores the use of an ultrasonic atomizer for generating the spray. Ultrasonic atomizers produce a narrow spray with very little kinetic

Table 1: Nominal operating conditions and design parameters.

Definition	Symbol	Value	Parameter	Value
Feed flow rate	V_{feed}	$25\text{ml}\,\text{min}^{-1}$	Height of the chamber	35 inches
Feed temperature	T_f	298K	Radius of the chamber	16 inches
Air temperature	T_a	644K	Height of cylindrical section	11 inches
Ambient Temperature	T_{amb}	298K	Air flow rate required	$33.9\ \text{g}\,\text{s}^{-1}$
Atomizer frequency	-	40kHz	Heat required	9 KW
Mean droplet size	d_p	60 μ	Thermal efficiency	57 %

energy as compared to conventional atomizers and they also provide a very narrow particle size distribution. A representative particle is tracked as it passes through the chamber. The size is obtained by calculating the distance travelled once it exits the atomizer to the point where the droplet satisfies the product requirement The product requirements (e.g., size) chosen for the design may be different for different products.

Simultaneous solution of the heat and mass transfer balances inside the chamber and inside the representative droplet provide the heating and drying gas flow rate requirements. Particle tracking is accomplished using a Lagrangian approach but the drying gas properties is modeled using empirical correlations available for the circular geometry chosen for the chamber. This approach reduces the computational burden to solve the model and also avoids artificial dispersion that may occur if an Eulerian approach was used instead [3]. The heat and mass transfer equations for the chamber are a system of ordinary differential equations (ODEs). The single droplet model is a system of three partial differential equations (PDEs) describing the temperature and concentrations of both the solute and solvent inside a representative droplet. As the droplet temperature changes as it passes through the chamber, the droplet undergoes heating and evaporation. In the latter case, the solvent evaporates resulting in a decrease in the size of the droplet. As a consequence a moving boundary problem has to be solved during evaporation. The numerical approach used here is the Gradient Weighted Moving Finite Element method [4].

3. Example Design

An ultrasonic atomizer is chosen as the atomizing device due to size restrictions on the spray chamber. Air is selected as the drying gas that is introduced tangentially to the droplet solution inside the chamber. The nominal operating conditions and design parameters are shown in Table 1. The primary sizing criterion is that the solvent concentration inside the particle must be less than 10%. Other criteria such as particle size and tap density are also compared and found to match the experimental results quite well.

The rate of solvent evaporation and the temperature of the dryer outlet dictate the sizing of the chamber and hence are important design variables. In addition, since the final product is to be a hollow particle, the inlet air temperature has to be sufficiently large so that a “skin” is formed but its formation should not degrade the solute. The air temperature predicted by the model is simultaneously compared to experimental data taken from a laboratory scale unit. These quantities are shown in Figure 1a and 1b, respectively.

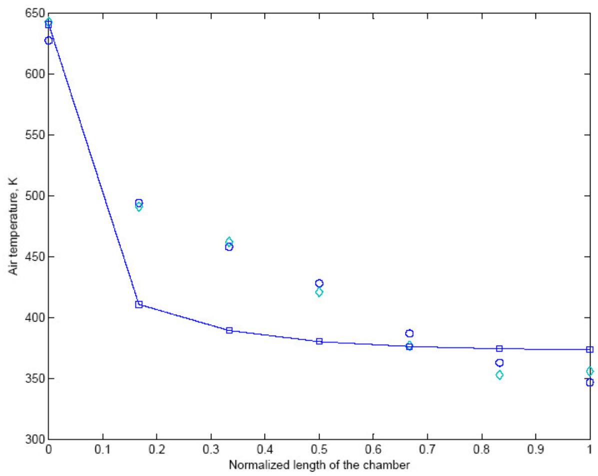

Fig1.a: Air temperature inside the chamber.
(□: model, ♢, ◦: data)

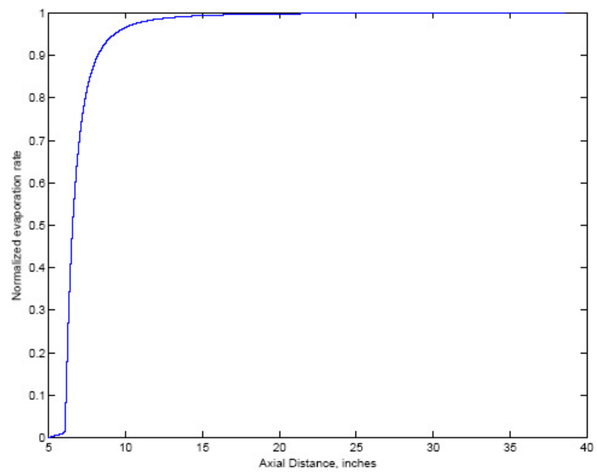

Fig 1.b: Evaporation rate inside the chamber

4. Summary

In this work, a design method for spray chambers based on a rate-based approach was presented. The design model and the single-droplet model are solved to provide design parameters for a spray drying chamber for the manufacture of hollow particles. The design criterion is that the solvent concentration inside the particle must be less than 10%. The model predictions are found to be in satisfactory agreement with the experimental data.

References Cited

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