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Entropy production during the drying process of milk droplets in an industrial spray dryer

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ABSTRACT

Development of high energy efficiency spray dryers is of great importance for the future of the dairy powder industry. The present research studied energy efficiency in an industrial scale spray dryer with the second law of thermodynamics. The entropy production rate is computed from the CFD modeling results of the transient multi-phase flow in the spray dryer. Influences of particle size, inlet air flowrate and inlet air temperature on the entropy production rate are analyzed. The results show that large particles produce more entropy per unit mass on dry basis. To decrease the moisture content of product powders, it will produce more entropy by increasing inlet mass flowrate than by increasing the air temperature. The study shows that the second law of thermodynamics is a potential tool for optimizing dryer operation and design.

1. Introduction

Spray dryers are widely used in the dairy industry to produce dry powders from liquids. The capacity of spray dryers in the dairy industry is from one ton to some twenty tons of dry powder produced per hour. Therefore, spray dryers in general require large amounts of energy. Design of high performance spray dryers that are more energy efficient and yet can maintain high quality is a challenging task. There are a number of methods that can be applied to enhance heat transfer between gas and milk particles such as increasing the inlet gas mass flow rate and temperature, enlarging the dryer size or enhancing turbulence. But which method is the most energy efficient? The conventional definition of energy efficiency doesn't reflect the quality of the energy. For example, it doesn't reflect the difference between kinetic energy and thermal energy. The second law of thermodynamics is a good tool for comparing different kinds of energy and assessing energy efficiency in spray dryers. According to the second law of thermodynamics, a system which produces the least entropy by irreversibilities destroys the least amounts of available work. Thus, entropy production can be used as an energy efficiency parameter in a thermal system, so as to optimize the dryer design and operation.

The second law of thermal dynamics has already been employed in the assessment of a number of combustion [1,2], evaporation [3] and heat/mass transfer problems [4–7]. There are some recent reports on application of entropy analysis on drying processes [8,9]. However, there is still a lot of work to do in this field, for example, the coupling of the entropy analysis with a CFD solution.

The objective of the present paper is to study the entropy production in an industrial scale spray dryer. The inlet moisture content and the output moisture content are usually fixed so that the entropy production in the dryer is independent of the external processing parameters. An entropy study can help to optimize dryer operating parameters by minimizing the entropy production rate. The optimization procedure is based on the initial interpretation of the second law of thermodynamics. On one hand, efficiency of a spray dryer decreases with increases in entropy production. On the other hand, the spray drying process must satisfy the quality and yield requirements of the particles. Thus, the optimized procedure should produce the least entropy while the exiting particles should satisfy the requirements of plant operation.

Influences of particle size, the inlet hot air temperature and mass flow rate on entropy production rate will be analyzed based on numerical results. The multi-phase flowfield in the spray dryer is simulated with the CFD commercial software FLUENT 6.3. Here the three-dimensional multiphase and multi-species flow is simulated. The Eulerian-Lagrangian approach for dispersed multiphase flow is

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