A generalized conjugate model for forced convection drying based on an evaporative kinetics

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ABSTRACT

A model describing the heat and mass transfer involved in food drying is presented. The aim is to determine the effect of air temperature on the performance of the drying process applied to fresh-cut vegetable slices, but other effects can be easily incorporated in the model. The model allows to disregard one of the most limiting parameters in such modeling, i.e. the average heat and mass transfer coefficients at the food/drying substrate interface, which are generally taken from the literature. Such assumptions are limiting in the sense that they are referred to average transfer coefficients at a general geometry. The presented model relies upon a finite-element solution of time-dependent differential equations for simultaneous and conjugate heat and moisture transfer in a two-dimensional domain, without any inference in such empiricism.

A special formulation for drying kinetic of the substrate is also exploited, and a treatment of the dependence of the properties upon the residual moisture content is included. After proper validation with the available experimental measurements, the numerical solution is discussed by presenting each involved field variables, emphasizing on the conjugate nature of the drying process. Due to its flexibility and generality, the model can be used in common industrial driers’ optimization, even in the assumption of a laminar flow field.

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1. Introduction

Drying, or dehydration, is one of the most common methods of preserving food, and involves a complex combination of transport phenomena such as the application of heat and the removal of moisture from a food substrate (Barbosa-Cánovas and Vega-Mercado, 1996; Fellows, 2000). Drying systems optimization is still sought nowadays and therefore full understanding of these phenomena can help to improve process parameters and hence product quality, emphasizing on the external and internal process parameters that influence drying behavior. The former include temperature, velocity and relative humidity of the drying medium (air), while the latter include density, permeability, sorption-desorption characteristics and physical substrate properties.

Starting from the seminal works by Luikov and Whitaker a vast number of contributions has been reported in the last decades on porous and multi-phase media drying by air convection (Chen and Pei, 1989; Barbosa-Cánovas and Vega-Mercado, 1996). But in the past few years the multi-dimensional (distributed, transient) analysis has gained importance, specially for lumped moist products, as a considerable computing power became more available, therefore many such studies could be conducted and finalized.

Shapes and detailed configurations were explored through a variety of approach, though always appealing to empirical, average (i.e. independent on surface locations) relationships for interface transfer calculations.

These limitations affected many of the available works on drying modeling in the last decade, as briefly recalled in the following. Wang and Chen (1999) presented a thorough diffusive model of heat and mass transfer in moist media, yet limited to a one-dimensional geometry. Chen et al. (1999) developed a finite element model for coupled heat and mass transfer, to implement the thermal processing of chicken patties in a small convection oven with cooking condition and empirical, nonlinear thermal properties. Dincer and his co-workers have presented a great deal of works on the subject in the past and recently (Kaya et al., 2006), where the simultaneous heat and mass transfer have been studied for the spatial variations of the heat and mass transfer coefficients along the treated surface. Pasta drying was studied by Migliori et al. (2005) on an axisymmetric geometry, followed by De Temmerman et al. (2008) who added a radiation driving force. A finite-element approach was employed by Avéria et al. (2007) in order to optimize the drying process by accounting for local temperature variation of both air and food physical properties.

As drying is evidently a conjugate phenomenon (which means, the transfer of mass and heat is solved simultaneously in both solid and fluid phases, and are strongly coupled through evaporation