FOOD PROCESSING MODELS

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Contents

Summary

The importance of food process modeling cannot be underestimated because of its potential to significantly impact safety, quality, and operations from a social-economic perspective. The overview presents a snapshot of the theoretical background and modeling approaches relevant to selected food processing applications. This chapter is not a comprehensive review but rather an outline of the notable advances made so far through case studies of selected processes such as infrared, microwave, ohmic (resistance) heating, plate heat exchanger, and mixing.

1. Introduction

Food processes may seem flourishingly diverse at the outset, but the core lies in the movement of heat and mass, mechanics of materials, and transmission of electromagnetic fields. The diverse processes could be broken down into small number of unit operations. Important unit operations in the food industry are fluid flow, heat transfer, drying, evaporation, contact equilibrium processes (which include distillation, extraction, gas absorption, crystallization, and membrane processes), mechanical separations (which include filtration, centrifugation, sedimentation and sieving), size reduction, mixing and stretching. Because of the dependence of unit operations on these physical principles or a sub group of associated principles, quantitative relationships in the form of mathematical equations could be developed for product and process optimization (Earle, 1983).

Food process models possess the intrinsic opportunity of reusability and parameter transferability. Modeling allows the exploration of product characteristics when subject to extreme as well as intermediate conditions without the use of actual materials, thereby saving valuable time and cost of operation. Since 2000, a move towards incorporating chemical and microbial kinetics into the engineering design to model the biochemical phenomena in food systems is on the rise. Such a comprehensive approach should also be supplemented by "product functional" characteristics, the modeling of which is very complex and may not be necessary.

More importantly, the practical application of food process models in industries could be of immense benefit for the development of new processes and for communication between people with different backgrounds, i.e. scientists, engineers, and technologists. Some models are used to provide "ball-park" estimates or rather provide qualitative information while other fundamental models describe the occurrence or evolution of a phenomenon. A seemingly simple example such as the diffusion of moisture transport (Dr. Datta's group in Cornell University) through an apple skin could become involved because of the complex and heterogeneous structure of agricultural and food materials (Dr. Nicolai's group in Leuven). In a practical situation, models that are specific to a product and a process have the potential and promise of real monetary benefits. We will illustrate through examples the diverse nature of modeling food systems, using the concept of heat and mass transfer.

2. Modeling Basic Transport Process and Kinetics

The analysis of heat and mass transfer in porous bodies has been the subject of intense theoretical and experimental research since the 1950s. The complexity of modeling a food system is due to the nature of ingredients and the structure-function relationships. For example even in a very simple starch-sugar system, sugars normally compete with starch for water, upon heating and affect the heat and mass transfer process, yet sugar has a function. Hence adding crystalline fructose to food products, particularly in water-limited food systems, will affect the physical and thermal properties because it reduces the water activity which in turn affects the drying rate (Sterling, 1978, Irudayaraj, and Wu, 1998), thus illustrating the coupling nature of chemical transport. When food safety considerations are imposed, modeling should incorporate microbial kinetics. Marks et al. (1999) and Murphy et al. (2001) incorporated thermal destruction models for *Salmonella* into a coupled heat and mass transfer model for convection cooking of chicken patties.

Mathematical modeling and simulation of product temperature, cooking yield, and pathogen lethality during and actual processing could be a valuable tool for designing effective and safe thermal processes. Erdogdu et al. (2001) optimized the double-sided cooking of hamburger patties using the Modified Complex Method which completed the mathematical formulation for the objective functions and constraints such as plate temperature and target lethality. Scheerlinck et al. (2001) and Van Impe et al. (1995) discussed coupled heat and mass transfer problems and a proposed dynamic model to predict microbial growth and inactivation under varying time-temperature conditions. Use of an advanced Computational Fluid Dynamics (CFD) model of the process has been shown to be beneficial for uniformity of heating and the reduction of moisture accumulation, ensuring the sterility of food inside the oven (Verboven, et al., 2003). Such and other selected processes will be explored through case studies.

2.1. Case Study 1: Modeling Heat Transport and Fungal Inactivation Kinetics during IR Heating

Infrared (IR) radiation has been applied to various food processing operations such as dehydration, preservation and pasteurization of food materials. Despite its great potential, few of the past works have dealt with the manipulation of IR radiation and its relationships to optical characteristics of food (Shuman and Stanley, 1950; Alden, 1992; Lentz et al., 1995). IR radiation can be controlled or filtered to allow radiation within a specific spectral range to pass through using suitable optical bandpass filters. Such a controlled radiation can stimulate the maximum optical response of targeted object when the emission band of IR radiation and the peak absorbance band of the targeted object are identical. Jun and Irudayaraj (2003a and 2003b) have examined the transfer of heat due to IR radiation, to illustrate the concept of a novel selective heating approach to food processing. A very simple governing partial differential equation provided below illustrates this concept (Fig. 1):

$$\rho C_{\mathrm{p}} \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial z^2} - \frac{\partial q_{\mathrm{r}}}{\partial z} \quad (1)$$

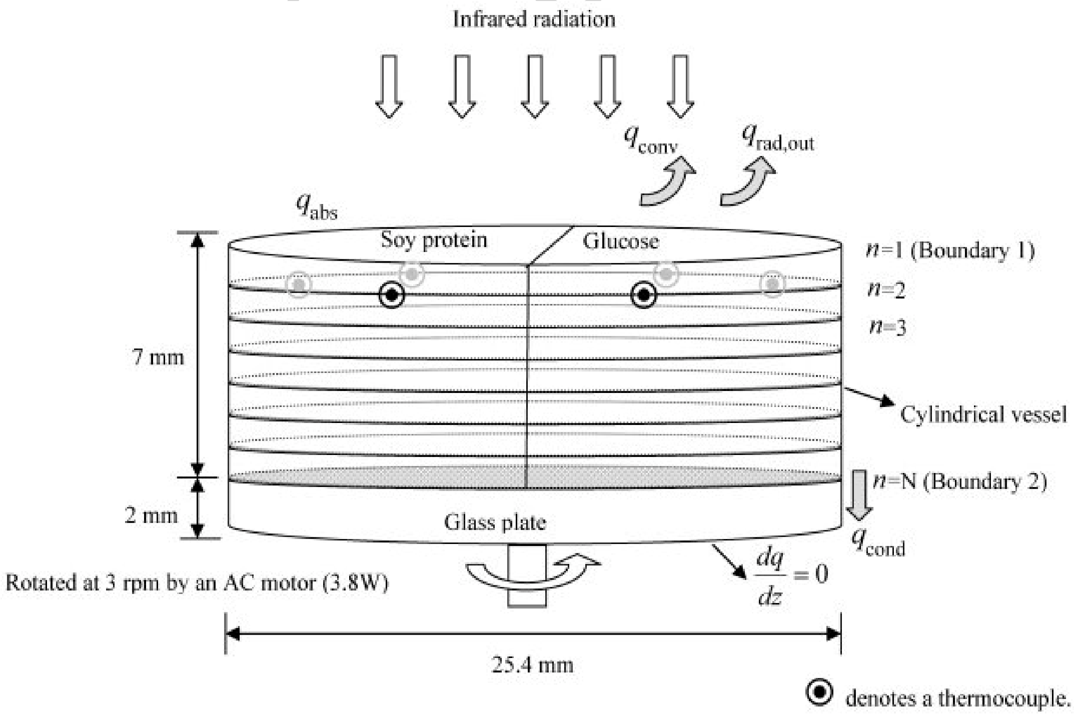

Figure 1: Schematic of a discretized food domain on a holder

Here q_r is the heat flux, T is the temperature, ρ is the density, C_p is the specific heat of food sample, k is thermal conductivity, t is the time, and z is the distance. The source term, q_r denotes the penetrative decay of radiative energy and optical responses of food components which have a spectral dependence. The amount of heat flux absorbed by the food surface is dependent upon the spectral absorptivity (α) of food, the spectral distribution of filtered infrared radiation and the view factor as the fraction of incident energy reaching food surface, and can be expressed as,

$$q_r(n) = F\,\alpha(\lambda)\,\tau(\lambda)\,q_{\text{incident}}\exp\left(-S\,\Delta z\,(n-1)\right) \qquad (2)$$

Where τ is the filter transmissivity which is a function of wavelength (λ), $q_{incident}$ is the incoming IR heat flux, S is the extinction coefficient, and Δz is the grid size. Model predictions of temperature values obtained in this study were consistent with the experimental data, ensuring that the IR radiation can be controlled using an optical filter for selective absorption of heat by the corresponding components (Jun and Irudayaraj, 2003a).

Fungal inactivation with selective IR heating

Based on the concept of selective IR heating, Jun and Irudayaraj (2003c and 2004) incorporated the fungal inactivation kinetics with their heat and mass transfer models to study the inactivation of *Aspergillus niger* in corn meal. They presented a thermal death kinetics model to predict the survival of fungal spores for a given temperature as

$$N_i / N_0 = \exp\left(-\int_0^t C_1 \exp\left(-\frac{C_2}{T(t)}\right) dt\right) \qquad (3)$$

Where N_0 is the initial spore count, N_i is the count at any heating time 'i', T is the absolute temperature, t is the time, and C_1 and C_2 are the empirical coefficients (Table 1). The prediction accuracy of the survivor spores depends upon food temperature, as Eqs. (1) and (3) can be interactively coupled. The spectrum based model for selective IR heating confirmed that an increased thermal dose and the denaturation of specific protein bands are key contributors to the enhanced lethality of the spores.

Fungal spore / IR condition	*Aspergillus niger*		R^2	*Fusarium proliferatum*		R^2
	C_1	C_2		C_1	C_2	
Without filter	4.666×10^6	6701	0.998	2.755×10^5	5809	0.997
With filter	6.456×10^3	4402	0.999	9.317×10^2	3786	0.995

Table 1: Empirically determined coefficients, C_1 and C_2 for the thermal death kinetics model (Jun and Irudayaraj, 2003c)

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