Chapter 5
Modeling of Heating During Food Processing

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5.1 Introduction

Heat transfer processes are important for almost all aspects of food preparation and play a key role in determining food safety. Whether it is cooking, baking, boiling, frying, grilling, blanching, drying, sterilizing, or freezing, heat transfer is part of the processing of almost every food. Heat transfer is a dynamic process in which thermal energy is transferred from one body with higher temperature to another body with lower temperature. Temperature difference between the source of heat and the receiver of heat is the driving force in heat transfer.

To conduct effective process modeling there is a need for consistent thermo-physical property information.

5.2 Thermal Properties of Foods

The thermal properties of food products determine their ability to transfer and store heat. The thermal properties are specific heat, $C_p$ (J/kg/K), thermal conductivity, $k$ (W/m/K), and thermal diffusivity, $\alpha$ (m²/s).

5.2.1 Specific Heat

Specific heat is a measure of the amount of energy required by a unit mass to raise its temperature by a unit degree. So, specific heat is the quantity of heat that is gained or lost by a unit mass of product to accomplish a unit change in temperature, without a change in state. It can be calculated as follows:

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\[ C_p = \frac{Q}{m\Delta T}, \quad (5.1) \]

where \( Q \) is the heat gained or lost (kJ), \( m \) is the mass (kg), \( \Delta T \) is the temperature change in the material (K), and \( C_p \) is the specific heat (kJ/kg/K).

Specific heat is an essential part of the thermal analyses of food processing or of the equipment used in heating or cooling of food. A number of models express specific heat as a function of water content, as water is a major component of many foods. Siebel (1892) proposed that the specific heat of food materials such as eggs, meats, fruits, and vegetables can be taken as equal to the sum of the specific heat of water and solid matter. One of the earliest models to calculate specific heat was proposed by Siebel (1892) and Charm (1978). Siebel’s model is described by the following equation:

\[ C_p = 0.837 + 3.349W, \quad (5.2) \]

where \( W \) is the water content expressed as a fraction of the total base.

The influence of product components was expressed in an empirical equation proposed by Charm (1978) as

\[ C_p = 2.093X_f + 1.256X_s + 4.187W, \quad (5.3) \]

where \( X_f \) is the mass fraction of fat and \( X_s \) is the mass fraction of nonfat solids.

Other equations of form similar to that of Eq. 5.2 have been summarized by Sweat (1986).

Choi and Okos (1986) suggested a more generalized equation for specific heat which takes into account the composition of food:

\[ C_p = 4.180W + 1.711X_p + 1.928X_f + 1.547X_c + 0.908X_a, \quad (5.4) \]

where \( X \) is mass or weight fraction of each component and the subscripts denote the following components: \( p \) – protein, \( f \) – fat, \( c \) – carbohydrate, and \( a \) – ash.

Although specific heat varies with temperature, for ranges near room temperature, these changes are relatively minor. They are usually neglected in engineering calculations. Sweat (1986) gave several equations for specific heat which include temperature dependency.

### 5.2.2 Thermal Conductivity

The thermal conductivity of a food material is an important property used in calculations involving the rate of heat transfer. Thermal conductivity \( k \) is the rate of heat