CHAPTER 7

POUCH PRODUCT QUALITY

7.1. BACTERIA INACTIVATION IN FOOD POUCHES DURING THERMAL STERILIZATION

The analysis of inactivation of *Clostridium botulinum* during thermal sterilization of pouches (Ghani et al., 1999a) is extended to cover *Bacillus stearothermophilus*. *B. stearothermophilus* has greater heat resistance than other microorganisms encountered in foods, and its inactivation means that all other contaminants are inactivated also. The spore’s viable count measured after different heating periods (Chapter 8) is compared with those predicted theoretically. Concentration profiles of *B. stearothermophilus* during natural convection heating of a food in a three-dimensional (3-D) pouch are also presented.

The death of microorganisms is expected to begin at an early stage of heating at locations near the wall, where the temperature approaches 121°C very quickly. While at other locations, the temperature may not rise until a much later time, experiencing a much lower rate of destruction. Hence it is necessary to solve the partial differential equation (PDE) governing the bacteria concentration, coupled with the equations of continuity, momentum, and energy in order to predict the overall destruction of microorganisms.

In the simulation presented in this chapter, natural convection heating of different viscous liquid foods in a 3-D pouch heated from all sides is presented. A computational procedure was developed for describing the changes in live bacteria concentration and its transient spatial distributions during sterilization processing of canned food. All liquid foods used were assumed to have constant physical properties except for the viscosity (temperature dependent) and density (Boussinesq approximation). The Arrhenius equation was used to describe the kinetics of bacteria death and the influence of temperature on the inactivation rate constant. It was introduced to the software package using FORTRAN code. The implementation of bacteria kinetics in computational fluid dynamics (CFD) code PHOENICS using *q1* and *Ground.f* coding is similar to those used for the can shown in Appendix B.

7.1.1. Fundamental Equations and Physiochemical Properties

7.1.1.1. Mathematical Model

The PDEs governing natural convection motion of fluid in a 3-D pouch are the Navier–Stokes equations in *x*, *y*, and *z* coordinates (Section 6.1.3). In addition to these equations, the following equation for the concentration of bacteria is introduced:

**Mass balance for bacteria (concentration equation)**

\[
\frac{\partial C_{rb}}{\partial t} + v_x \frac{\partial C_{rb}}{\partial x} + v_y \frac{\partial C_{rb}}{\partial y} + v_z \frac{\partial C_{rb}}{\partial z} = D \left[ \frac{\partial^2 C_{rb}}{\partial x^2} + \frac{\partial^2 C_{rb}}{\partial y^2} + \frac{\partial^2 C_{rb}}{\partial z^2} \right] - k_{T_b} C_{rb} \quad (7.1)
\]
where $C_{rb}$ represents the relative concentration of viable bacteria in the pouch at any time and location. It is taken as a dimensionless species concentration, which is defined as the ratio of real-time concentration $C_b$ to the initial concentration $C_{bo}$ multiplied by 100.

At the top surface, bottom surface, and side walls all the concentration gradients $\frac{\partial C_{rb}}{\partial x}$, $\frac{\partial C_{rb}}{\partial y}$, and $\frac{\partial C_{rb}}{\partial z}$ are set equal to zero.

Other boundary conditions for temperature and velocities were as follows:

$$T = T_w, \quad v_x = 0, \quad v_y = 0, \quad \text{and} \quad v_z = 0$$

Initially the fluid is at rest and is at a uniform temperature.

The initial conditions used in this case with the concentration were as follows:

$$T = T_0, \quad v_x = 0, \quad v_y = 0, \quad \text{and} \quad v_z = 0 \quad (7.2)$$

$$C_{rb} = C_{rb0} = 100, \quad v_x = 0, \quad v_y = 0, \quad \text{and} \quad v_z = 0 \quad (7.3)$$

where $T$ is the temperature of the liquid food, $T_w$ is the pouch wall temperature, $T_0$ is the food initial temperature, and $C_{rb0}$ is the initial relative concentration of bacteria.

The assumptions used to simplify the problem were similar to those used in Section 5.2.1.4. The additional assumptions used were as follows:

1. The bacteria concentration can be assumed to be low, and hence, the effect of the interactions upon their diffusion can be ignored.
2. The diffusion coefficient of the live bacteria is assumed to be identical for live and dead bacteria.

At the early stages of this work, two simulations were performed for two cases in which the Brownian motion of bacteria was ignored in one of them. No significant differences were observed between the two cases. The calculated diffusion coefficient for bacteria was of order $10^{-12}$ m$^2$ s$^{-1}$ (Chapter 5), which is low due to the high viscosity of most liquid food. The cell Peclet number, $Pe$ (ratio of convection to diffusion), for bacteria within the flow domain in the $z$-direction was calculated and found to be of the order of $10^4$, which allows the Brownian motion of bacteria to be ignored.

The computations were performed for a 3-D pouch with a width ($W$) of 120 mm, height ($H$) of 40 mm, and length ($L$) of 220 mm. The pouch outer surface temperature (top, bottom, and sides) was assumed to rise instantaneously and to be maintained at 121°C throughout the heating period. The pouch volume was divided into 6000 cells: 20 in the $x$-direction, 10 in the $y$-direction, and 30 in the $z$-direction, as described in Appendix E. The total simulation time used for the sterilization of carrot-orange soup was 3000 s as the total heating period, and it was divided into 30 time steps. The time steps used were same as those reported in Chapter 6 (Section 6.1.2). For beef-vegetable soup, the total simulation time used for the sterilization was 1800 s, with 18 equal time steps only.

7.1.1.2. Bacteria Inactivation Kinetics

The rate of bacteria inactivation is usually assumed to follow first-order kinetics (Reuter, 1993). The inactivation rate constant for bacteria $k_{Tb}$ is a function of temperature and is usually described by