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Food preservation process design

Dennis R. Heldman*

Heldman Associates, Mason, OH, U.S.A.

Abstract

Preservation processes for food products have evolved over time as more fundamental information about the factors influencing the processes have become available. Traditionally, thermal processes have been used for preservation of both shelf-stable and refrigerated foods. Recently, ultra-high pressure (UHP) and pulsed-electric-field (PEF) technologies have been considered as alternative processes. The objective of this paper is to discuss the integration of kinetic models for microbial inactivation and quality retention with appropriate models for transport phenomenon within the product structure, to predict the impacts of the processes on microbial populations and product quality attributes. As food safety concerns in refrigerated foods have increased, the amounts of kinetic data on microbial survivors during both traditional and alternative processes have increased. In addition, similar data for survival of pathogenic spores under UHP and PEF processes have been measured and published. During the same period of time, new physical properties data for foods have been published, along with predictive models for transport phenomenon within food products. Through the integration of appropriate kinetics models with models for transport phenomenon, the design of preservation processes has been improved and optimized.

Keywords: kinetics; physical properties; process design; quality optimization; alternative processes

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1. Introduction

Food preservation processes have evolved over significant periods of time. The evaluation and design of these processes has become quantitative, based on the results from scientific research on the processes. This paper will focus on the quantitative evaluation of preservation processes for food products. The process design concepts to be presented will build on the long and successful history of thermal process design, but will extend the analysis to combination processes and to non-thermal technologies, such as ultra-high pressure and pulsed electric fields. In addition, the analysis will include concepts needed to estimate the impact of a process on food components, including nutrients and other product quality

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* Corresponding author. Tel.:+203-770-0508.
E-mail address: drheldman@earthlink.net.

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attributes. Finally, the opportunities for optimization of preservation processes to achieve process efficiency and product quality retention will be explored. The overall objective of this paper is to review the latest available information on design of preservation processes, with specific attention to kinetics of microbial inactivation, transport phenomenon within the product structure, and the impacts of the processes on microbial populations and product quality attributes.

2. Process Design Models

2.1. Kinetic Models

The models available for application to preservation processes include kinetic models to describe changes in microbial populations, as well as changes in quality attributes [Heldman (2)]. During any preservation process, most components of the food are impacted in some manner. These impacts can be described quantitatively, by models based on reaction kinetics. The models describe the impact of the process on the microbial populations (both pathogens and spoilage) in the product, and the product quality attributes.

2.1.1 Microbial Kinetics

The first-order model to describe the change in microbial population as a function of time is:

$$N = N_o \exp(-k\, t) \tag{1}$$

where N is the population at any time (t), N_o is the initial population and k is the first order rate constant. Preservation processes based on the use of thermal processes have used the following form of the first-order model:

$$N = N_o\, 10^{-t/D} \tag{2}$$

where D = decimal reduction time.

A direct relationship between the Decimal Reduction Times (D) and the first-order rate constants (k) exists. More recently, models to account for the influence of non-log-linear microbial survivor curves on process design have been proposed. One of the models proposed for non-log linear microbial survivor curves is:

$$\log N_o - \log N = [\, t / D' \,]^n \tag{3}$$

where D’ is a time constant similar to the Decimal Reduction Time (D) and “n” is a coefficient to account for deviations from a log-linear relationship.

A typical model used to describe the influence of temperature on the rate constant is the Arrhenius equation :

$$k = k^o \exp[- E_A / R\, \mathbf{T}\,] \tag{4}$$

where k^o is a pre-exponential factor, R is the gas constant , **T** is absolute temperature , and E_A is the activation energy.

Pressure has emerged as a potential preservation technology, and the intensity of pressure will impact the rates of inactivation for microbial populations. The expression proposed for this relationship is:

$$k = k^o \exp[\, - \Delta V\, P / R\, \mathbf{T}\,] \tag{5}$$

where P is pressure, R is the gas constant, k is the rate constant, **T** is absolute temperature, and ΔV is the activation volume (m^3/mole). When the magnitude of ΔV is negative, the reaction rate increases with increasing pressure.

2.12 Quality Attributes

In general, the changes in food quality attributes during a preservation process are described by the same kinetic models as presented for microbial populations. The interest in applications of these models has increased as concerns about retention of food quality attributes during preservation processes have become more evident. The magnitude of most kinetic parameters for quality attributes indicates that the use of higher temperature processes for shorter time will improve quality retention while still achieving the goals of the preservation process.

Villota and Hawkes (5) has presented an excellent review of the reaction kinetics associated with changes in quality attributes in foods. Changes in vitamin concentration during preservation processes, storage and distribution have been described in terms of first-order kinetics, and the kinetic parameters include first-order rate constants and activation energy constants. Similar kinetic parameters for retention of pigment intensity during preservation processes, storage and distribution have been assembled. These kinetic parameters for retention of quality attributes in foods should be viewed as representative of the retention of the most product quality attributes.

2.2. Physical Transport Models

The intensity of the preservation processes can be detected by measurement of one or more physical parameters within the product. These parameters can be predicted by physical transport models, based on product composition. Ultimately, these models can predict the intensity of the process parameter at any location within the product structure.

The design of a preservation process depends on physical properties of the product and associated physical phenomenon. The application of a thermal process depends on the transport of thermal energy within the product structure in order to achieve the temperature increase required for the process, and the decline in temperature during cooling of the product. The application of an ultrahigh pressure process requires the application of the pressure to the product structure and the uniform distribution of pressure throughout the product structure. In addition, the thermal energy associated with an increase in pressure will result in an increase in temperature, and the resulting temperature distribution within the product must be analyzed.

The applications of the transport phenomenon models for prediction of temperature distribution histories within a food product structure depend on access to reliable physical properties data. The relationships published by Choi and Okos (1) provide reliable physical properties of foods, based on product composition. During unsteady-state heat transfer, the temperature is a function of time and location and the following solution of the appropriate partial differential equation [Pflug, et al (3)]:

$$\log (T_a - T) = - t/f_h + \log [j_c (T^a - T_i)] \tag{6}$$

where the magnitudes of the two parameters (f_h, j_c) can be evaluated experimentally or predicted from physical properties of the product and the boundary conditions during the process. The parameters can be predicted from relationships with the Biot Number:

$$N_{Bi} = h\, d_c / k \tag{7}$$

where d_c is a characteristic dimension, h is the surface heat transfer coefficient and k is the thermal conductivity of the product. The magnitude of the Biot Number ranges from less than 1.0 to over 40, depending on the limiting conditions for heat transfer. The characteristic dimension (d_c) applies to all geometries, and is the shortest distance from the geometric center to the surface.

3. Preservation Models

3.1. Preservation Process Design

The models for design of a preservation process involve the integration of the appropriate kinetic model with the appropriate physical transport model. Although there have been limited attempts to demonstrate quantitative process design for prediction of changes food quality attributes, the approach can be used in process optimization.

The process for preservation of a food product is dependent on the target reduction in microbial population, and the physical phenomenon causing the reduction in microbial population. Models for description of the preservation process require an integration of a model to predict reductions in microbial population, with a model for prediction of the intensity of the physical phenomenon within the product mass. The output from the integration is the process time. The impact of the process on quality attributes of the food product will be evaluated using the same integration steps.

3.2. Application of Models

The preservation process time is the time required to that ensure microbial population is reduced to a target level. Although this would suggest a straight-forward application of the survivor curve equation, the definition of the appropriate process time must account for the location within the product mass, and the variability in the intensity of the physical phenomenon within the product structure. Most of the quantitative guidance for development of process time for preservation processes has been derived from the design of thermal processes (commercial sterilization) for shelf-stable foods. The process time is important for the operator of the process, and the specific process conditions associated with ensuring that the thermal process reduces the target microbial population to the target level.

The published literature for thermal processes provides the basis for integration of kinetic models with models for transport phenomena. Although the general approach will applied to alternative preservation technologies, the concepts may be illustrated using the traditional thermal process. Most often, these processes are based on first-order survivor curves. If the survivor curve is not a first-order model, an appropriate alternative model should be selected. In addition, an appropriate expression should be selected to predict the changes in a quality attribute of the food product during the process.

More specific expressions for prediction of the temperature distribution history within the product during thermal processes depend on geometry of the product (and/or package/container). For liquid foods, the expressions are unique for the heat exchanger used for the process. For non-thermal preservation processes, appropriate alternative expressions would be selected to describe the distribution of agent intensity of within the product structure as a function of time.

3.3. Optimization of Processes

Although the primary purpose of a preservation process is to ensure food product safety or acceptable levels of product spoilage, the impact of the process on product quality attributes is receiving increased attention. Due to the differences between various preservation processes, the impacts on product quality are different. These differences should be considered and minimized during the design of the preservation process. In general, a more intense preservation process is expected to be more detrimental to the quality attributes of the food product. This is most evident with thermal processes, when higher temperatures accelerate the losses of temperature-sensitive food components. All processes must be carefully evaluated using the kinetics parameters of the target microbial populations as well as similar parameters of the temperature-sensitive product quality attributes. The relationships between the magnitudes of the kinetic parameters for microbial populations as compared to the parameters for quality attributes create unique opportunities for optimization of these processes. Process optimization is defined as the process needed to ensure product safety or acceptable spoilage rate, while providing a maximum retention of a product quality attribute.

The concept of optimization for thermal processes for conduction-heating food products was illustrated by Teixeira, et al (4). The results of this investigation demonstrated that a unique temperature-time process can be identified for maximum retention of a quality attribute. More specifically, the retention of thiamine in a conduction-heating product during thermal processing in a can is maximum at a defined temperature-time process. The results were obtained by comparing a series of processes where the combination of heating medium temperatures and process times provide the same reduction in a defined microbial population at the geometric center of the container. The retention of thiamine was maximum when the heating medium temperature was 122 C for 80 min. Equivalent processes, with higher temperatures for shorter times or lower temperatures for longer times, resulted in lower retention of thiamine. The thiamine retention was based on mass or volume-average concentration within the product container.

4. Conclusion

The concepts associated with quantitative design of preservation processes have been established with the design of thermal processes for shelf stable foods. The process design is based on the use of appropriate kinetic models to describe the reduction in microbial populations in the product, as well as the retention of product quality attributes. These models are integrated with models to describe the appropriate transport phenomenon models for the process, and the physical properties of the product. These approaches apply to design of traditional thermal processes, as well as most alternative preservation processes. In addition, the approach provides the opportunity to optimize the process design by maximizing the retention of product quality attributes, while ensuring the microbial safety of the product or the acceptable product shelf-life.

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