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Optimum on-line correction of process deviations in batch retorts through simulation

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Abstract

This paper describes broader applications of computer-based batch retort control systems that make use of mathematical models to accomplishing on-line correction of unexpected process deviations in thermal processing of low-acid canned foods. Current systems over extend process time with costly consequences to product quality and retort operating schedules in cook room operations. These problems are addressed by describing novel control strategies that also treat the retort temperature as a control variable, rather than just process time alone. On-line correction is accomplished by choosing an optimum higher constant retort temperature for the remainder of the process that will deliver the specified target lethality within the original process time remaining. The paper also describes on-line correction of process deviations occurring during a pre-programmed variable or dynamic retort temperature process that might be chosen to maximize nutrient retention in a conduction-heated food. In this situation, an optimum combination of retort temperature and process time is chosen for the remainder of the process that will deliver the maximum possible nutrient retention without compromising the specified final target lethality. Examples are given for the case of solid product undergoing a conduction-heating process in different shaped containers (cylindrical can and retort pouch), as well as liquid product undergoing forced convection heating in cylindrical cans under mechanical agitation.

Keywords: On-line control; Process optimization; Thermal process; Retort; Autoclave; Low-acid foods; Canned foods; Batch processing; Conduction heated; Forced convection; Process deviations; On-line correction

1. Introduction

Thermal processing is an important method of food preservation in the manufacture of shelf stable canned foods, and has been the cornerstone of the food processing industry for more than a century. Thermal process calculations, in which process times at specified retort temperatures are calculated in order to achieve safe levels of microbial inactivation (lethality), must be carried out carefully to assure public health safety (Ball, 1928; Bigelow, Bohart, Richardson, & Ball, 1920; Holdsworth, 1997; Pham, 1987; Stumbo, 1973; Teixeira, 1992). However, over-processing must be avoided because thermal processes also have a detrimental effect on the quality (nutritional and sensorial factors) of foods. Therefore, the accuracy of the methods used for this purpose is of importance to food science and engineering professionals working in this field. Control of thermal process operations in food canning factories has consisted of maintaining specified operating conditions that have been predetermined from product and process heat penetration tests, such as the process

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Nomenclature

A	area
a and b	constant of linear equation describing retort temperature profile ($\mathrm{TRT}(t) = a + bt$)
C_p	heat capacity of food
CUT	come-up time
E	energy per mass unit
F_0	sterilizing value at 121.1 °C
f	rate factor (related to slope of semi-log heat penetration curve)
f_h and f_c	heating and cooling rate factors (related to slope of semi-log heat penetration curve)
k	thermal conductivity of food
M	product mass
$\dot{Q}$	rate of heat transfer
T	temperature
T_{CP}	temperature in the coldest point
IT	initial temperature
TRT	retort temperature
T_r	reference temperature, 121.1 [°C]
t	time
U	global heat transfer coefficient

Greek letters

α	thermal diffusivity of food ($\alpha = k/\rho C_p$)
ρ	density of food
∇	differential or nabla operator ($\nabla = \partial/\partial x + \partial/\partial y + \partial/\partial z$)
∇^2	laplace operator ($\nabla^2 = \partial^2/\partial x^2 + \partial^2/\partial y^2 + \partial^2/\partial z^2$)

calculations for the time and temperature of a batch cook. Sometimes unexpected changes can occur during the course of the process operation such that the prespecified processing conditions are no longer valid or appropriate, and off-specification product is produced that must be either reprocessed or destroyed at appreciable economic loss. These types of situations are known as process deviations. Because of the important emphasis placed on the public safety of canned foods, processors must operate in strict compliance with the US Food and Drug Administration's Low-Acid Canned Food (FDA/LACF) regulations. Among other things, these regulations require strict documentation and record keeping of all critical control points in the processing of each retort load or batch of canned product. Particular emphasis is placed on product batches that experience an unscheduled process deviation, such as when a drop in retort temperature occurs during the course of the process, which may result from loss of steam pressure. In such a case, the product will not have received the established scheduled process, and must be either fully reprocessed, destroyed, or set aside for evaluation by a competent processing authority. If the product is judged to be safe then batch records must contain documentation showing how that judgment was reached. If judged unsafe, then the product must be fully reprocessed or destroyed. Such practices are costly.

According to the US Food and Drug Administration (FDA), a retort temperature deviation occurs when the retort temperature drops more than 0.5 °C below the one specified in the process registration file (Larkin, 2002). Therefore, processors of low-acid canned foods must have an effective and efficient control system over the retort sterilization process to avoid unexpected process deviations that would leave the resulting process lethality in question. With this kind of system, smooth uninterrupted operation of a retort battery system in large cook rooms is assured and human error due to manual operation is reduced. In general, commercial on-line control systems consist of three parts, data acquisition, computer software with control and computational algorithms, and the interface hardware. Only one computer is required to control a large number of retorts. The real-time display is available to the supervisor in graphic mode, may also be permanently stored in user-defined files, and can provide both automatic and manual control.

Commercial systems currently in use for on-line retort control accomplish on-line correction of process deviations by extending process time to that which would be needed had the entire process been carried out at the retort temperature reached at the lowest point in the deviation.

In addition to the versatility and relative simplicity of this control strategy, it is also clear that it will always result in a safe correction, but by no means optimal or efficient (Alonso, Banga, & Perez-Martin, 1993; Simpson, 2004; Von Oetinger, 1996). Recognizing this limitation a control logic algorithm, first conceived by Teixeira and Manson (1982) and further developed by Datta, Teixeira, and Manson (1986), was proposed for use with computer-based control systems on batch retort operations, that incorporated a mathematical heat transfer model to simulate heat conduction into a solid body in the shape of a finite cylinder. The proposed system was capable of automatically adjusting process time during the cook cycle to compensate for any unexpected deviation in retort temperature. The advantage of this system was that it was capable of implementing an exact or required correction for a process deviation without unnecessary over processing. However, the