



Short Communication

Computer Control of a Steam Surface Pasteurization Process*

Miriam Cygnarowicz-Provost, James C. Craig Jr & Richard C. Whiting

US Department of Agriculture, Agricultural Research Service, Eastern Regional Research Center, Philadelphia, PA 19118, USA

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ABSTRACT

Flash steam heating followed by evaporative cooling can be used to pasteurize only the surface of processed meat products. This paper describes a process control scheme used to determine the treatment time in a pilot-scale pasteurization chamber. The control system used a model for microbial death to compute, in real-time, the treatment time required to give products that have a specified reduction in the bacterial population. The system was tested by treating frankfurters inoculated with a known population of bacteria. With low inoculum levels, the control system was shown to give products that had the specified reduction in the bacterial population, and only minimal changes in the product appearance.

NOTATION

$k(T)$	Arrhenius constant for thermal death model
$\log \left(\frac{N}{N_0} \right)_{\text{spec}}$	Target reduction in bacterial population

*Mention of brand or firm name does not constitute endorsement by the US Department of Agriculture over others of a similar nature not mentioned.

N	Population of bacteria at any time, t (CFU/g)
N_0	Initial population of bacteria (CFU/g)
t	Time (s)
t_c	Treatment time (s)
T	Temperature ($^{\circ}\text{C}$)
T_{cool}	Target maximum temperature of frankfurter surface after evaporative cooling ($^{\circ}\text{C}$)
T_{max}	Maximum temperature of frankfurter surface measured during evaporative cooling ($^{\circ}\text{C}$)
T_{min}	Minimum temperature of frankfurter surface measured during steam heating ($^{\circ}\text{C}$)
$T_1(t), T_2(t), T_3(t)$	Temperature of frankfurter surface measured at three locations ($^{\circ}\text{C}$)

INTRODUCTION

The surfaces of meat and poultry are known to be sources of bacterial contamination. A pathogen of increasing concern is *Listeria monocytogenes*. It is widespread in nature, and has been isolated from various fresh foods such as milk, meats, fish, poultry and vegetables. It has also been found on processed meats, such as frankfurters (Wenger *et al.*, 1990). The organism has been shown to survive heating (Mackey & Bratchell, 1989) and refrigeration (Wilkins *et al.*, 1972).

We have investigated the use of flash steam heating followed by evaporative cooling to pasteurize processed meat products (Cygnarowicz-Provost *et al.*, 1994). The process is designed to quickly reduce the bacterial contamination on the product surface without introducing significant internal heating or degradation of its appearance or taste. The objective was to design a fast process that could be incorporated into current high-speed meat and poultry processing lines. We have initially treated beef frankfurters, because these products have a relatively smooth, regular shape. Although these are cooked products, they are at some risk from bacterial contamination. During processing, the microbial load in frankfurters is undetectable when they exit the smokehouse (Zaika *et al.*, 1990) but they may become contaminated at detectable levels during the peeling step, when the casing is removed. In fact, a recent outbreak of listeriosis has been attributed to the consumption of uncooked turkey frankfurters (Wenger *et al.*, 1990).

The acceptability of this new process will hinge upon the ability to deliver products that have undergone only minimal changes in the appearance or organoleptic quality. By using a thermal death kinetics model to compute the accomplished lethality, the minimum treatment time to obtain a desired reduction in bacterial count can be determined in real-time. Previous work utilizing on-line computation of process lethality has focused on the control of retorts (Navankasattusas & Lund, 1978; Teixeira & Manson, 1982; Datta *et al.*, 1986; Gill *et al.*, 1989). The objective of this work was to demonstrate that this approach can be used to control the extent of bacterial contamination on the surface of beef frankfurters.

The frankfurters were treated in a small pasteurizer, designed and constructed in our facility (Fig. 1). The treatment chamber consisted of a small diameter (50.8 mm) stainless-steel tube, equipped with five bare wire thermocouples (Teflon-coated, Type E, 0.25 mm diameter). The tips of the thermocouples protruded through the bottom of a Teflon mesh support. This support held the frankfurters in direct contact with the thermocouples. The difficulties encountered when experimentally measuring surface temperatures are well documented (Houghton & Olson, 1941). We used very small diameter thermocouple wires so that heat transfer to the surface would not be disturbed, and heat conduction away from the surface would be minimized. The thermocouples were connected to a multiplexer board (Model EXP-16, Omega Engineering, Stamford, CT) to amplify and condition the signal, and the multiplexer was, in turn, connected to a high-speed data acquisition board (Model DAS-16F, Omega Engineering, Stamford, CT) installed in a microcomputer. Three thermocouples were in contact with the product surface, and two were exposed to the chamber conditions. The thermocouples had a response time of 0.3 s and were scanned at a rate of 100 Hz, which made the lag time negligible.

A configuration of valves and switches was designed to rapidly fill and empty the chamber. The valves were controlled through a digital I/O board (Model CYDIO-24H, Cyber Research, Stamford, CT) installed in the microcomputer. The I/O board was connected to a solid-state relay board which could turn the power to the valves on or off depending on the signal from the microcomputer.

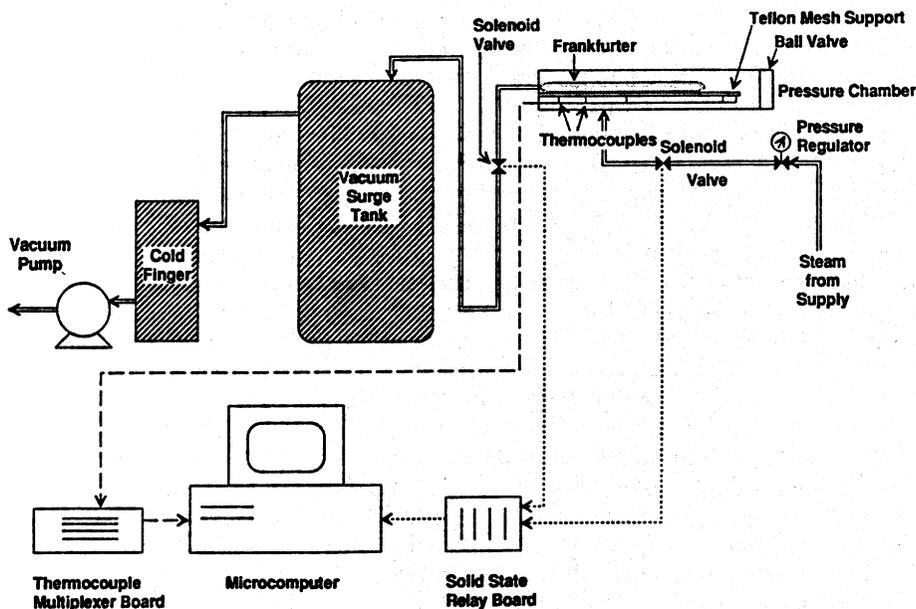


Fig. 1. Experimental apparatus for the surface pasteurization process.

A high-capacity vacuum pump (100 cfm @ 29 in Hg vacuum) was used to evacuate the chamber before and after the introduction of the steam. The inlet steam pressure was set using a regulator.

In the control scheme, the minimum surface temperature measured among the three thermocouples monitoring the frankfurter surface was used to compute the fraction of bacteria remaining at any time, t_e , according to

$$\log \left(\frac{N}{N_0} \right) = - \frac{\int_0^{t_e} k\{T(t)\} dt}{2.303}$$

where

$$k\{T(t)\} = \exp \left(126.5094 - \frac{43949}{T(t)} \right)$$

In the above equations, N is the population of bacteria (colony forming units (CFU)/g frankfurter) at any time, t , and N_0 is the initial population of bacteria. This first-order model assumes Arrhenius kinetics. The control system was programmed using the data acquisition software, Labtech Notebook (Laboratories Technology, Wilmington, MA). A flow diagram of the computer program logic is given in Fig. 2.

The control system thus computed the extent of the population decrease as the treatment time proceeded. When the specified decrease was achieved, the system vented the steam and activated the vacuum system to cool the frankfurter. Once the frankfurter surface was cooled to a specified minimum temperature, the control system isolated the chamber from the vacuum system, and the product was removed. The frankfurters were then weighed, and the color was measured using a color spectrophotometer.

Microbiological experiments were conducted to verify the efficacy of the process. Since the work was done in our food processing pilot plant, safety considerations dictated that a pathogenic bacteria could not be used. *Listeria innocua* (SA3-VJ, Buchanan *et al.*, 1989) a non-pathogenic strain, was utilized in all experiments. It has similar, but slightly larger, D -values than *L. monocytogenes* (Foegeding & Stanley, 1991). The organism was grown in 100 ml BHI/300 mg glucose solution at 28°C for 18 h. The frankfurters to be inoculated were placed in a sterile stomacher bag, the culture was added and the bag was slowly agitated for 10 min to allow adequate coverage of the surface. The frankfurters were then allowed to dry under a biological hood for 15 min. Immediately after heat treatment, the frankfurters were placed in a sterile stomacher bag and kept on ice until the plates could be prepared. To determine the population that remained after treatment, 100 ml of sterile 0.1% peptone water was added to the stomacher bags containing the treated frankfurters, and the bags were shaken for 2 min. The solution was then diluted and plated onto tryptose agar. This procedure has been shown to remove nearly all of the bacteria from the surface of frankfurters (Palumbo & Williams, 1991). The inoculum level on the surface was controlled by changing the concentration of bacteria in the medium. Three different inoculum levels were investigated: 10^7 ,

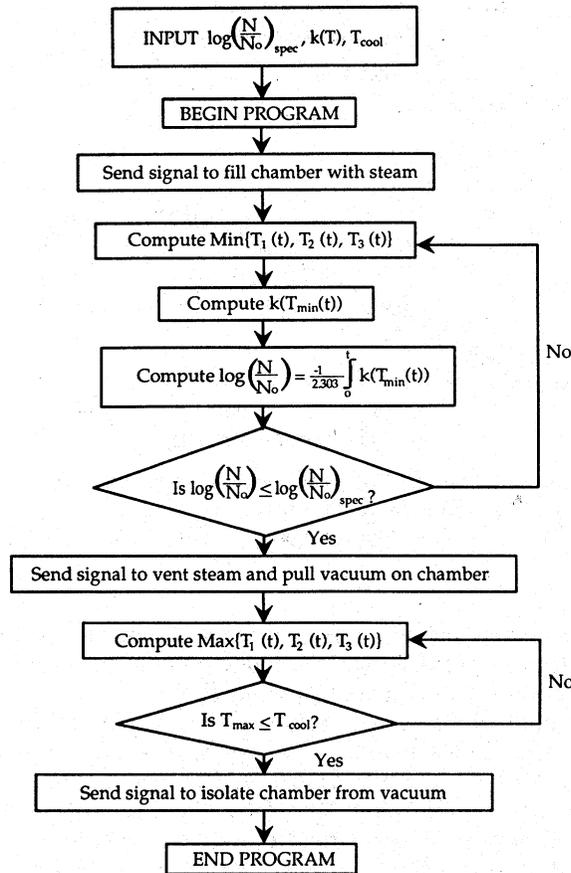


Fig. 2. Flow diagram of the computer logic for process control program.

10^5 , 10^4 CFU/g. Three inoculated and three uninoculated controls were used for each condition investigated. The inoculated controls were shown to contain on average 3.36×10^7 , 4.05×10^5 , and 1.76×10^4 CFU/g. The uninoculated controls were shown to contain no colonies.

RESULTS AND DISCUSSION

Unlike many of the other heat transfer processes presented in the literature, this is not a steady-state process. The 'come-up' time is an integral part of the treatment, since the goal is to keep the treatment time as short as possible to minimize product degradation. An example of the product surface and chamber temperatures observed during treatment to achieve a 4 log reduction with 115°C steam is shown in Fig. 3, along with the predicted microbial death curve for this temperature history. Only limited thermal death time data are available for *Listeria innocua* (Foegeding & Stanley, 1991) and to our knowledge, no data

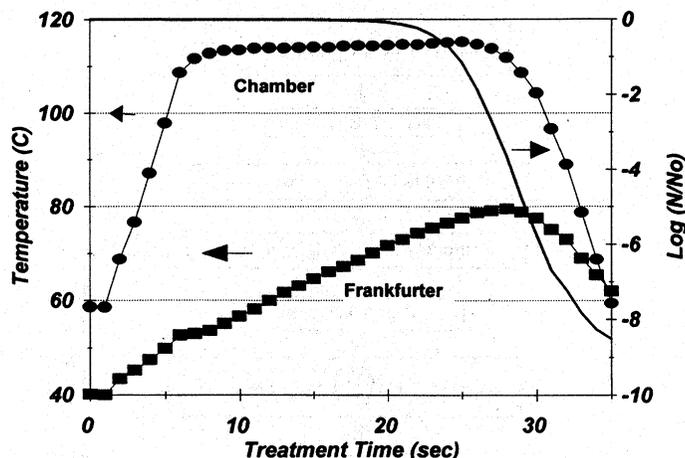


Fig. 3. Temperature histories of the frankfurter surface and chamber during treatment to achieve a 4 log reduction with 115°C steam. Also given is the microbial death curve predicted by the control program. Values are the average of 20 experiments.

are available for this organism in meat systems. Therefore, in this study, we used thermal death time data for *Listeria monocytogenes* in beef homogenates (Gaze *et al.*, 1989) to compute the rate constant, $k(T)$.

The process control system was tested with steam at 136 and 115°C, and the results are given in Tables 1 and 2. For $\log(N_0) = 4.25$, the reductions were on target, i.e. there were no colonies detected after treatment to achieve either a 4 log or a 10 log reduction. For $\log(N_0) = 5.61$, the 4 log specification was met for treatment at both temperatures. However, detectable colonies remained for the 10 log specification with 115°C. Similarly, when $\log(N_0) = 7.53$, the 10 log specification was not met for steam at either temperature, and the 4 log specification was not met for treatment with 136°C steam. These results are probably due to inaccuracies in the model predictions. The bacterial death rates were predicted by a simple, first-order model which did not represent the presence of a heat-resistant subpopulation. Such subpopulations lead to the phenomena of 'tailing' in thermal death time curves (Cerf, 1977). The tailing effect was not evident for the samples with $\log(N_0) = 4.25$, since the numbers of heat-resistant bacteria in these cases were too low to be detected. Inaccuracy in the estimation of the rate constant may have also led to the underprediction of the required treatment time. We used thermal death time data for *Listeria monocytogenes* in fresh beef homogenates to compute $k(T)$. However, *Listeria innocua* has been shown to be more heat-resistant than *Listeria monocytogenes* (Foegeding & Stanley, 1991) and sausage media has been shown to provide some protective effect for *Listeria monocytogenes* as compared with fresh meat (Schoeni *et al.*, 1991). We expect that control system performance would be improved if accurate thermal death time data were available for the target organism in the desired media.

We found the difference in treatment times between the 4 log and the 10 log cases to be small. As shown in Fig. 3, the exponential nature of the death

TABLE 1
Results of Process Control Tests with Steam at 136°C^a

$\log(N_0)$	$\log\left(\frac{N}{N_0}\right)_{spec}$	Target log (N)	Actual log (N)	t_e (s)
4.25	-4	0.0	0.0 (± 0.0)	20.2 (± 0.9)
5.61	-4	1.61	1.81 (± 1.0)	20.2 (± 0.9)
7.53	-4	3.53	5.23 (± 0.55)	20.2 (± 0.9)
4.25	-10	0.0	0.0 (± 0.44)	21.7 (± 1.0)
5.61	-10	0.0	0.0 (± 0.69)	21.7 (± 1.0)
7.53	-10	0.0	3.70 (± 0.79)	21.7 (± 1.0)

^aThe results are the average of two experiments, three samples per experiment. Confidence limits (90%) are in parentheses.

TABLE 2
Results of Process Control Tests with Steam at 115°C^a

$\log(N_0)$	$\log\left(\frac{N}{N_0}\right)_{spec}$	Target log (N)	Actual log (N)	t_e (s)
4.25	-4	0.0	0.0 (± 0.52)	30.3 (± 1.0)
5.61	-4	1.61	1.35 (± 1.1)	30.3 (± 1.0)
7.53	-4	3.53	3.99 (± 0.69)	30.3 (± 1.0)
4.25	-10	0.0	0.0 (± 0.0)	33.3 (± 0.9)
5.61	-10	0.0	1.72 (± 1.1)	33.3 (± 0.9)
7.53	-10	0.0	4.16 (± 0.74)	33.3 (± 0.9)

^aThe results are the average of two experiments, three samples per experiment. Confidence limits (90%) are in parentheses.

TABLE 3
Changes in Weight and Color of Beef Frankfurters after Surface Pasteurization^a

Steam temperature (°C)	$\log\left(\frac{N}{N_0}\right)_{spec}$	Weight loss (%)	Hunter L reading
136	-4	1.34 (± 0.37)	50.42 (± 0.77)
136	-10	1.31 (± 0.40)	51.28 (± 0.37)
115	-4	1.21 (± 0.36)	51.21 (± 0.53)
115	-10	1.28 (± 0.28)	50.91 (± 0.54)
Untreated			52.22 (± 1.4)

^aThe results are the average of two experiments, four samples per experiment. Confidence limits (90%) are in parentheses.

kinetics curve means that additional log reductions occur rapidly after the surface temperature begins to increase.

The changes in weight and color observed before and after treatment are shown in Table 3. There was no statistical differences noted among the different treatment targets. Weight losses averaged approximately 1.2–1.3% and the color variations were minimal. The color changes measured after treatment were within observed lot-to-lot variations in the Hunter *L* reading of untreated frankfurters (Cygnarowicz-Provost *et al.*, 1994).

Given the simplifications inherent in the model, however, the control system was surprisingly accurate. This study suggests that using a thermal death kinetics model to predict the on-line lethality of the surface pasteurization treatment can produce microbiologically safe, high-quality food products.

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