Ohmic cooking of processed meats: Energy evaluation and food safety considerations

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*[1]Université Laval, Faculté des Sciences de l'Agriculture et de l'Alimentation, Département des sols et de génie agroalimentaire, Québec, Québec G1K 7P4, Canada; [2]Agriculture and Agri-Food Canada, Food Research and Development Centre, 3600 Casavant Boulevard West, Saint-Hyacinthe, Québec J2S 8E3, Canada; and [3]Hydro-Québec, Laboratoire des technologies électrochimiques et des électrotechnologies, 600 Avenue de la Montagne, Shawinigan, Québec G9N 7N5, Canada. *Email: Damien.de.Halleux@sga.ulaval.ca*

de Halleux, D., Piette, G., Buteau, M.-L. and Dostie, M. 2005. **Ohmic cooking of processed meats: Energy evaluation and food safety considerations**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada 47: 3.41 - 3.47 An ohmic cooking cell prototype has made it possible to conduct rapid batch cooking of 1-kg Bologna ham. Cooking was carried out at a constant voltage of 64, 76, and 103 V, until product temperature along the unit longitudinal axis reached 71, 76, and 81°C. A high quality product may be obtained with cooking times between 10 and 15 minutes at temperatures between 70 and 81°C. Compared to conventional smoking methods, cooking times are reduced 90 to 95% with energy savings of 82 to 97%. Due to the rapid temperature rises (5 to 15°C/min), the pasteurization effect of the heating period is found to be small or negligible. In order to meet minimal pasteurization criteria, emulsions heated to a final temperature of 75°C will require a holding time of at least 15 minutes while at 80°C the holding time may be decreased to a minimum of five minutes.

Un prototype de cellule de cuisson ohmique a permis la cuisson rapide de jambon de Bologne en lot d'un kilogramme. L'émulsion de viande insérée dans la cellule de cuisson a été soumise à des tensions de 64, 76 et 104 Volts jusqu'à ce que les températures au centre de la cellule atteignent 71, 76 et 81°C. Les tests réalisés ont démontré qu'il est possible d'obtenir un produit de qualité avec des durées de cuisson comprises entre 10 et 15 minutes lorsque les températures sont comprises entre 70 et 81°C. Comparativement aux méthodes de cuisson traditionnelles en fumoir, les temps de cuisson sont réduits par 90 à 95% tout en permettant des économies d'énergie par 82 à 97%. Étant donné la grande vitesse de montée en température (5 à 15°C/min), on constate que l'effet pasteurisateur de la période de cuisson est négligeable ou faible. Afin de répondre aux critères de pasteurisation minimum, l'émulsion portée à une température finale de 75°C devra subir une durée de chambrage d'un minimum de 15 minutes tandis qu'à 80°C la durée de chambrage pourra être réduite à un minimum de 5 minutes.

INTRODUCTION

The current industrial process for cooking ham is still based on the centuries old conventional cooking principle of the smoke house. This leads to cooking times as long as six or eight hours and is accompanied by considerable energy consumption (Singh 1986). The surface areas devoted to production and storage must also be very large. The perfection of a rapid cooking method in which cooking and holding times combined were less than 30 minutes would correspond to a 90 to 95% reduction in cooking time. Obviously, such a method would have to preserve the organoleptic and microbiological qualities obtained by the conventional cooking method. Among the various possible methods for rapid cooking, we have developed and tested a laboratory scale cell using resistance heating for the rapid cooking of Bologna ham. Application of ohmic heating to solid foods has proven a greater challenge, and the concept has not yet led to commercial applications in the meat sector. Due to difficulties to maintain steady state cooking during long periods of times, earlier developments of ohmic equipment were abandoned (Vanhatalo et al. 1978).

The passage of an electric current through a food heats by the Joule effect. Indeed, the food behaves as a resistor in an electrical circuit. This type of heating, also known as Ohmic heating, has interested researchers for over a century. Although the technique appears both simple and advantageous, several difficulties are encountered in its application. Towards the end of the nineteenth century (Jones 1897) and during the first half of the twentieth century (Fetterman 1928; Ball 1937), various processes for the thermal treatment of liquids by resistance heating were developed.

An electrical current will pass through a food only if sufficient free ions are present to provide electrical conductivity. The use of direct current is less effective because of the occurrence of electrolysis, due essentially to the exchange of electrons at the contact surface between the food and the electrodes. Alternating current is more suitable and in fact creates an oscillatory movement of ions, which generates the heat dissipation underlying the resistance-heating phenomenon. According to Eq. 1, the thermal power dissipated inside the food resistor is proportional to the square of the current applied through the electrodes, the electrical resistance of the food, and a shape factor which characterizes the geometry of the device used to apply the current.

$$P = RI^2 K \tag{1}$$

where:

P = thermal power dissipated inside food (W),
I = current applied through electrodes (A),
R = electrical resistance of the food (Ω), and
K = shape factor of device used to apply current.

It is to be noted that the resistivity (ohm/m), or its more commonly used reciprocal known as conductivity (siemens/m), is the main parameter of the food influencing its capacity for resistance heating. Numerous researchers (Mitchel and De Alwis 1989; Halden et al. 1990; Palaniappan and Sastry 1991;

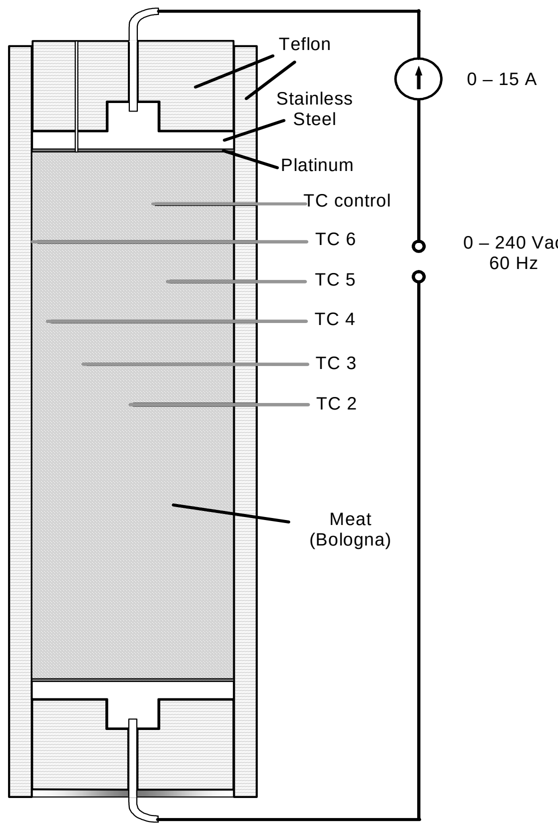

Fig. 1. Schematic representation of the ohmic cooking unit.

Wang and Sastry 1997; Bellmer et al. 1999; Marcotte et al. 2000a) have studied the influence of this parameter. Most foods containing mineral salts and having sufficient water content (>70%) are electrical conductors and thus may be heated by resistance heating. The conductivity of such foods is typically between 0.1 and 10 S/m. Pure fats and oils, bone, and crystalline structures (ice) are poor conductors or non-conductors of electricity. Given the major influence of fat and salt content on electrical conductivity, we paid particular attention to these two components in the composition of the tested emulsions.

In contrast with more conventional methods of heating, resistance heating is characterized by heat dissipation within the mass of the product with the absence of hot surfaces. Unlike heating by microwave or high-frequency radiation, depth of penetration is not an issue, since the heat is generated uniformly throughout the product exposed to the electric field. Due to variation in electric resistance from one product to another, the main disadvantage of resistance heating is that its application varies from product to product, with a consequent rise in development costs. Indeed, a universal device that can be used with all resistance-heatable foods does not exist. Various applications have been developed for heating viscous fluids or liquids, both in continuous and in batch mode. Among those worthy of mention are the heating column for liquids containing suspended particles (liquid-particle mixtures) developed by the Electrical Research Council at Capenhurst, United Kingdom (Biss et al. 1989) and commercialized by APV Baker (Peterborough, UK). For heating solids, few if any commercial devices are currently available.

If the heated medium, as it is in the case of meat emulsions, has a homogeneous conductivity between the electrodes, heating will be uniform. There will be no temperature gradients and therefore no heating by conduction, convection, or radiation from hot zones towards cool zones. This makes it possible to heat foods very rapidly (5 to 20°C/min) without altering food properties by over-heating. In the case of heterogeneous media (liquid-particle mixtures), the current passes preferentially through certain zones thereby creating temperature gradients (e.g. between fluid and solid particles). Simulation in 2D and 3D and mapping of the liquid-particle mixture temperatures have been the subject of numerous studies (Ye et al. 2003; Speller et al. 1999; Marcotte et al. 2000b; Eliot-Godéreaux et al. 2001; Davies et al. 1999; Ruan et al. 1999; Sastry and Salengke 1998). In view of the existing commercial applications and food safety considerations, several authors (Tucker et al. 2002; Uemura and Isobe 2002; Cho et al. 1996a, 1996b; Kim et al. 1996; Larkin and Spinak, 1996) have studied resistance heating as a pasteurization device with emphasis on the response of the microbial pathogens in liquid-particle mixtures.

The purpose of this article is to demonstrate the potential use of a resistance-heating cell for cooking Bologna ham as well as the associated energy and pasteurization efficiencies.

MATERIALS and METHODS

Heating cell

The heating cell (Fig. 1) designed in our laboratory was made of a Teflon cylinder with an inner diameter of 76 mm, a height of 305 mm and a wall thickness of 8 mm. The two removable electrodes by which the ham sample was held inside the cell were made of high-titanium stainless steel. The electrode surface in contact with the food was coated with platinum to minimize corrosion. The minimal tolerance between the electrodes and cylinder wall provided an adequate seal. The upper electrode had a 0.5 mm hole for air displacement.

Temperature measurements were conducted using 1.6 mm-thick Teflon-coated Copper-Constantan thermocouples (OMEGA Engineering, Stamford, CN) inserted through six holes drilled through the upper half of the cylinder. An additional thermocouple was used to measure the temperature of the external surface of the cylinder. A data acquisition system (Fluke, Model 2635A, Fluke Corporation, Everett, WA) was configured to log temperature, voltage, and current readings every 10 seconds.

The power supply allowed voltage to be adjusted at the electrode terminals. Its capacity was 240 VAC (60 Hz) at 15 amperes. Voltage was set manually using a potentiometer based on readings of the amperage and voltage.

Emulsion preparation, cooking, and cooling

Pork trimmings and fat were purchased at a local abattoir, frozen (-20°C), and vacuum-packed. Trimmings in 3.3-kg bags and fat in 1.3-kg bags were thawed in a cold room for two days at 4°C followed by a third day in a refrigerator at 1°C. The emulsion was prepared in a vacuum cutter (Stephan, model VCM-12, Stephan u. Söhne GmbH Co., Hameln, Germany) no more than two hours before each cooking treatment. The fat content of the trimmings was determined according to the Soxhlet method, using a Soxtec System (model 1043, Tecator, Höganäs, Sweden). The moisture content was measured by weighing a sample (50 g) before and after drying at 105°C to constant mass. Each batch was prepared in order to obtain an

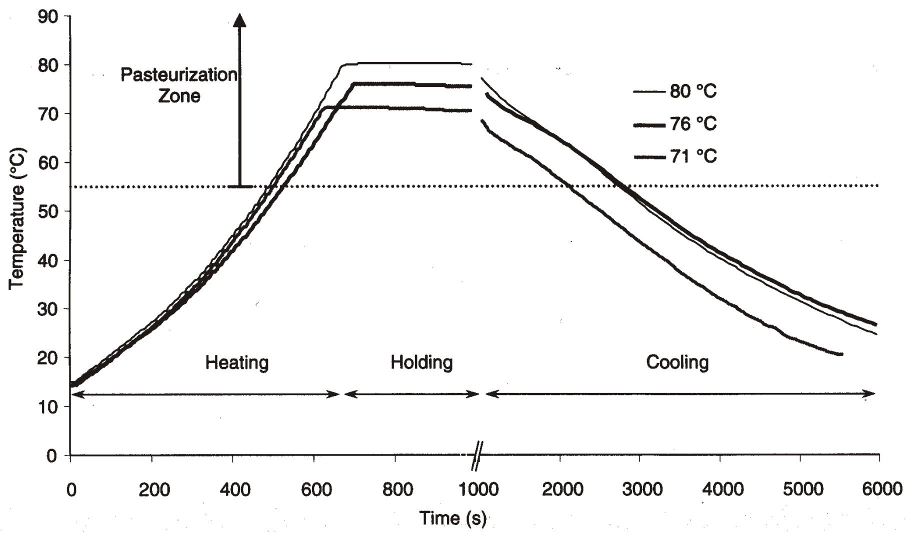

Fig. 2. Temperature profile inside Bologna emulsion for three set points (71, 76, and 81°C).

emulsion containing 22.0% fat and 2.05% salt (1.7% NaCl, 0.32% $NaNO_2$ and 0.07% sodium erythorbate).

The cell was filled at 4°C by suction using a SP25 piston stuffer (Villa SARL, Pantin, France) equipped with a 35 mm diameter stuffing horn in order to ensure uniform electrical contact between the electrodes and emulsion and to minimize the presence of air bubbles. This was achieved using a compression spring of adjustable tension which exerted a pressure of 275 kPa on the upper electrode. Filled cells were weighed to ensure that they contained 1 kg of emulsion (±0.050 kg). The height of the emulsion column was thus constant at 0.22 m for each test.

Connection of the electrodes to the power supply and of the temperature sensors to the data acquisition device as well as heating were conducted at room temperature (20 ± 1°C). Heating was initiated by applying voltage to the packed cell. Voltage was held constant until the temperature set point was reached, at which time the constant voltage application was interrupted to allow the cell to remain at a constant temperature for a five-minute holding period, during which the power supply was disconnected. The cell was then cooled by immersion in a stirred ice-water bath (0°C). As soon as the temperature at the geometrical centre reached 20°C, the cell was placed in a cold room at 1°C. Twenty-four hours later, the ham was removed from its mould in darkness and vacuum-packed. To be representative of market delays, ham was subjected to qualitative tests 14 days later to observe the effect of the resistance heating on product pH, a_w, colour (L a b), texture (TPA) and rancidity (TBA values) and weighed again to determine losses due to running or evaporation (Piette et al. 2004). All these measurements were determined in three replicate experiments.

The specific heat of the emulsion was determined according to the Differential Scanning Calorimeters (DSC) method, using a Thermal Analysis Instrument (TA Instrument, Model DSC 2910, New Castle, DE).

For purposes of pasteurization and in order to retain optimal organoleptic characteristics, (gelling, coagulation of proteins), the core temperature of Bologna hams obtained by the conventional smoke house method varies from 68 to 71°C. An initial series of three cooking trials with three repetitions was therefore conducted in order to reach a temperature of 71°C in 5, 10, and 15 minutes and to visually examine the resulting product taste and tactile qualities. These cooking times were obtained by applying fixed voltages of 103 , 76, and 64 volts, respectively.

To improve the pasteurization value while keeping the cooking time near to 10 minutes, we performed a second series of test at cooking temperatures of 76 and 81°C.

RESULTS and DISCUSSION

Figure 2 shows the time-temperature profiles of Bologna ham emulsions heated to final temperatures of 71, 76, and 81°C. In each case, the rise in temperature up to the set point occurred over approximately ten minutes (600 seconds) with a five-minute (300 seconds) holding time. It is apparent in this Fig. 2 that the temperature ramp is not constant even though the voltage is. This is likely due to increasing electrical conductivity and therefore increasing current as the temperature rises. During the five-minute holding period, a slight decrease (0.8°C) in core temperature occurred due to the diffusion of heat into the ambient air.

Energy aspects

Table 1 shows the electrode-applied voltage, final core temperature, heating time, heating rate, total and specific energy consumption, and energy efficiency for the various cooking conditions tested in triplicate.

For the emulsion used in the present study, regression of the voltage and current measurements indicates that the conductivity, σ (S/m) evolves as a function of temperature, T (°C) following a line defined as:

$$\sigma = 0.13 + 0.0039T \qquad (R^2 = 0.996) \qquad (2)$$

From Eq. 2, which is valid for temperatures from 15 to 80°C, it is apparent that conductivity is multiplied by a factor of 2.6 between these two temperatures. This large variation in conductivity explains the difference between the minimal and maximal currents measured (Table 1).

The rate of temperature increase shown in Table 1 is the average rate calculated in the pasteurization zone (temperature > 55°C). The values obtained correspond to rates of 5.0, 7.5, and 13.3°C/min for applied voltages of 64, 76, or 103 V, respectively. These temperature increase rates will have an impact on the pasteurization value attributable to the heating period. It was also observed that the most rapid cooking (5 minutes, 13.5 °C/min) resulted in structural defects and the formation of heterogeneous zones within the cooked ham. Although it would be technically possible to do the heating in less than five minutes, this time would appear to be the

Table 1. Cooking parameters and energy characteristics.

	Voltage (V)	Final temperature ± sd (°C)	Current (A)		Heating time ± sd (s)	Heating rate (°C/min)	Cooking energy ± sd (kJ)	Specific cooking energy ± sd (kJ kg^{-1} $°C^{-1}$)	Energy efficiency (%)
			min	max					
1	64	71.0 ± 0.25*	2.57	5.33	14.56 ± 0.20	5	211 ± 4	3.80 ± 0.09	71
2	76	71.3 ± 0.09	3.13	6.67	9.92 ± 0.31	7.5	213 ± 1	3.76 ± 0.04	72
3	103	71.6 ± 0.14	4.07	9.20	5.63 ± 0.15	13.3	220 ± 10	3.89 ± 0.13	68
I	76	71.3 ± 0.09	3.13	6.67	9.92 ± 0.31	7.5	213 ± 1	3.76 ± 0.04	72
II	76	76.1 ± 0.09	3.00	6.70	11.06 ± 0.37	7.5	233 ± 6	3.86 ± 0.08	70
III	76	81.4 ± 0.64	2.77	7.10	11.50 ± 0.64	7.5	252 ± 9	3.82 ± 0.04	71

*Number of replicates, n=3

threshold that should not to be crossed. In contrast, cooling is slower, occurring at rates from 0.6 to 0.9°C/min. Conduction is the primary mode of heat transfer during the cooling phase and the insulating effect of the cooking cell Teflon wall combined with the small conductivity coefficient of the processed meat explains the relative slowness of this phase.

The energy required to cook Bologna ham is thus between 211 and 252 kJ/kg using our device, the amount of energy increasing with the final temperature. Data reported in the literature for conventional smoke cooking of Bologna hams indicate between 1200 and 8100 kJ/kg (Reichert and Thumel 1986; Singh 1986; Reichert, 1991). Resistance heating would therefore allow a reduction in total energy consumption on the order of 82 to 97% with respect to conventional smoke cooking.

The specific energy of cooking was the average quantity of electrical energy that was transmitted into the cell to raise the temperature of one kilogram of emulsion by one degree Celsius. It can be seen that this energy was relatively constant and near to 3.8 kJ kg^{-1} $°C^{-1}$. The specific heat of the emulsion measured between 15 and 80°C by the DSC method for 20 samples averaged 2.7 kJ kg^{-1} $°C^{-1}$. Taking this value to be the average specific heat, the energy efficiency of resistance heating was therefore about 70±2% for all of the cooking conditions.

The temperature distribution throughout the product at various times during cooking is shown in Fig. 3. It can be seen that except for the regions immediately adjacent to the cooking

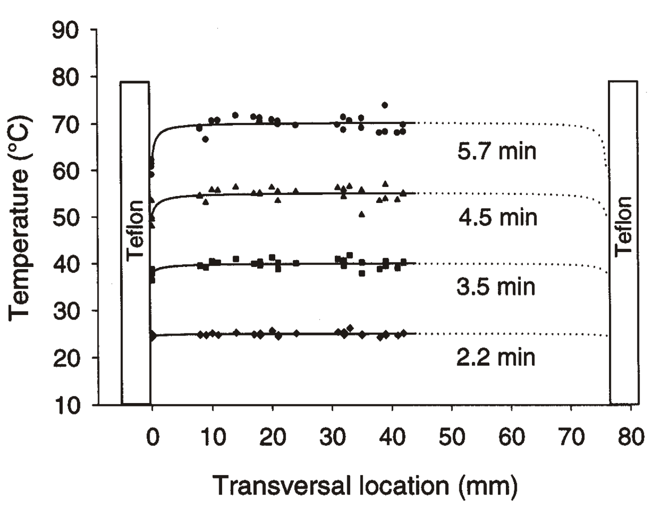

Fig. 3. Temperature profile across the product section at different times during heating.

cell walls (within 5 mm), the temperature was fairly constant throughout the product and reached values of 25.0±0.4°C after 2.2 minutes of cooking, 40.0±0.8°C after 3.5 minutes, 55.0±1.1°C after 4.5 minutes and 70.0±1.5°C after 5.7 minutes. As cooking progressed, a temperature gradient between the cell wall and the product mass core arose and increased with time, ranging from 0.4°C after 2.2 minutes to 2.3, 4.8, and 9.1°C after 3.5, 4.5, and 5.7 minutes, respectively. This gradient reflected an increasing wall heat loss as temperature increased. The temperature gradient measured between the internal and external wall surfaces shows that the heat lost was used mostly to raise the temperature of the cell wall, initially equilibrated at the emulsion temperature of 12°C. The amount of heat stored in the wall, which was between 55 and 60 kJ, constitutes the main portion of the energy unavailable for heating the meat. This suggests that it should be possible to obtain efficiencies greater than 90% in an industrial process in which these losses are controlled by wall insulation.

Pasteurization values

In addition to producing desired organoleptic effects through cooking, the purpose of heating the emulsion is also to contribute to food preservation and safety by decreasing the level of bacterial flora. The most common way of determining the level of microbiological security associated with a cooking process is to determine the pasteurization value at the coolest point inside the material throughout the process. This process may be divided into three phases: the heating phase (temperature rise), the temperature holding phase, and the cooling phase. In an industrial ohmic heating process with feed-back temperature control via the vessel walls during the rise phase, the temperature throughout the product should be uniform during the first two phases. However, the rate of temperature decrease during cooling, which occurs through conduction, should be proportional to the proximity to the vessel wall. The pasteurization effect due to temperatures greater than 55°C should therefore no longer exist outside the cylinder as soon as the cooling phase begins. Only the analysis of the pasteurization values from the first two phases shall therefore be considered in the present study of cooking through ohmic heating.

In marinated meats, the reference microorganism usually targeted is *Streptococcus faecalis* (Reichert et al. 1979). The D70 value for this bacterium in this medium is 2.95 minutes (the time required at 70°C to obtain a decimal (90%) reduction in viable numbers) while the Z value (the temperature increase

Table 2. Pasteurization values (minutes) during heating, holding, and heating + holding phases.

	Heating rate (°C/min)	Final temperature ± sd (°C)	Pasteurisation value (min)		
			Heating phase	Holding phase	Heating + holding
1	5	71.0 ± 0.25*	0.83	4.84	5.67
2	7.5	71.3 ± 0.09	0.57	5.82	6.39
3	13.3	71.6 ± 0.14	0.33	7.93	8.26
I	7.5	71.3 ± 0.09	0.57	5.82	6.39
II	7.5	76.1 ± 0.09	1.77	15.96	17.73
III	7.5	81.4 ± 0.64	5.83	70.77	76.10

*Number of replicates, n=3

required to reduce required heating time by 90%) is 10°C. The total pasteurization value is thus determined by:

$$P_t = \int_{t_{T55+}}^{t_{T55-}} 10^{(T-70)/10}\, dt \qquad (3)$$

where

P_t = total pasteurization value,

T = temperature of the product (°C),

t_{T55+} = start time for pasteurization, at which T passes 55°C, and

t_{T55-} = end of pasteurization, at which T drops below 55°C

Taking 13 decimal (log cycle) reductions as the pasteurization criterion (Reichert et al. 1979), the minimal pasteurization value required will be 13 x 2.95 = 38.35 or almost 40 minutes.

Table 2 gives experimentally obtained pasteurization values (heating and holding phases) for the three heating rates and final cooking temperatures. During the heating phase, these values are relatively small (less than two minutes), except for temperatures over 80°C.

The experimental values are similar to those calculated by simulation. The simulation (Fig. 4), representing five temperature rise speeds (15.0, 12.5, 10.0, 7.5, and 5.0 °C/min), allows the pasteurization values during the cooking phase to be determined as a function of heating time and four final cooking temperatures (70.0 to 85.0°C).

It is apparent from Fig. 4 that the slowest heating rate (5.0°C/min) allows the final cooking temperatures to be reached in about 14 to 16.5 minutes for 70 to 85°C while even the highest cooking temperature can be reached in a little over five minutes with the faster heating rates. It is also apparent that during the heating phase alone, pasteurization values greater than five minutes are obtained only with slow heating and final temperatures of 80°C or higher. For cooking done at temperatures beyond 80°C in the laboratory with a ramp of 7.5°C/min, the pasteurization value obtained is slightly over five minutes, which corresponds to the value obtained from the graph. Likewise, the pasteurization values of cooking below 75°C are very small regardless of the temperature ramp.

Consequently, in terms of the pasteurization effect, the heating phase may be considered, in practice, to be an instantaneous rise in temperature for temperatures not exceeding 80°C.

It is therefore the holding phase that will make the most significant contribution to the preservation of the food by significantly reducing the bacterial flora. Given the short time (five minutes) in our case, it is to be expected that the pasteurization values obtained during the holding phase (Table 2) will also be smaller, except when the temperature has exceeded 80°C. It follows that, with the exception of the latter treatment, the sum of the pasteurization values (heating + holding) will never be sufficient to achieve the projected 40 minute pasteurization equivalent. The holding period must therefore be increased in order to achieve a safe level of pasteurization.

To determine a safe holding time and the impact of this period on the pasteurization value, Fig. 5 provides curves for equivalent pasteurization values at temperatures between 70 and 85°C. The curves are included in the range between 25 and 150 minutes for holding times of less than 30 minutes. If, for example, a temperature of 75°C is maintained for a holding time of 15 minutes, a pasteurization value approaching 45 minutes will be obtained; if a temperature of 80°C is maintained, a pasteurization value near to 150 minutes will be obtained.

If the desired goal is a minimum 40-minute pasteurization equivalent, only temperatures above 75°C can achieve this in 15 minutes or less. Below this temperature, the time required to meet this specification immediately becomes very large. Likewise, it becomes apparent that rapid cooking (less than 30 minutes) may be ruled out. The 40-minute pasteurization equivalent may be achieved in only five minutes or less when the holding temperature is above 80°C. It is also beyond this temperature that

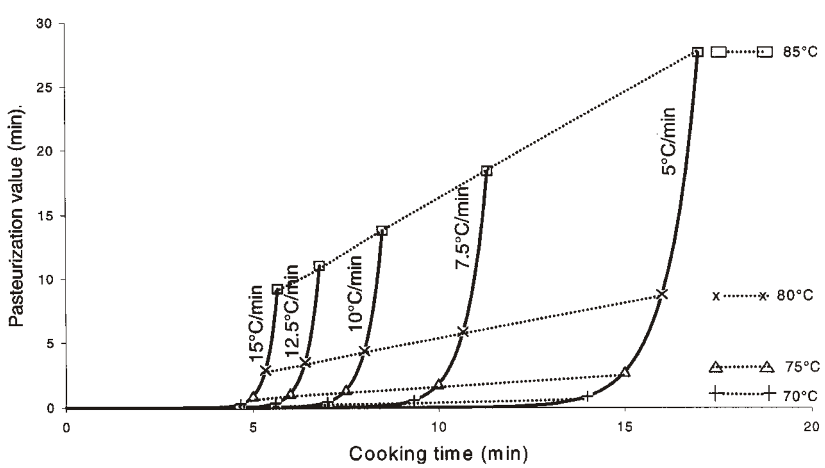

Fig. 4. Pasteurization value during the cooking phase as a function of heating time for five temperature rise rates (15.0, 12.5, 10.0, 7.5, and 5.0°C/min) and four final temperatures (70, 75, 80, and 85°C). D_{70} = 2.95 minutes and Z=10°C.

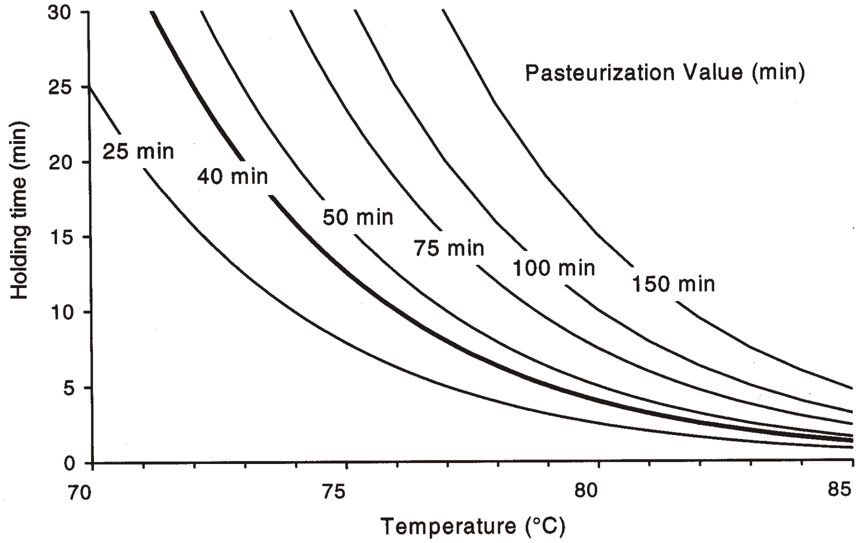

Fig. 5. Curves of the given pasteurization value for different temperatures between 70 and 85°C as a function of holding time.

pasteurization equivalents greater than 100 minutes may become possible even within the temporal requirement of rapid cooking.

By combining Figs. 4 and 5, it becomes possible to determine the range of temperature rise rates, final cooking temperatures, and holding times necessary to meet a predetermined pasteurization specification. For any given specification, the final choice of values for these three parameters may be adjusted within the allowed ranges in order to meet organoleptic specifications or other constraints on final product characteristics.

CONCLUSION

The development of a prototype ohmic heating cell has made rapid cooking of Bologna hams possible on a laboratory scale. The tests and simulations carried out with this prototype have allowed us to specify the ranges of heating rates, final temperatures, and holding times required to obtain a quality product meeting minimal pasteurization specifications. When compared to the traditional smoke-house cooking method, the cooking time was reduced by 90 to 95%, producing quality Bologna hams for which final cooking temperatures between 70 and 85 °C were reached within approximately 10 to 15 minutes. It was also determined that a heating rate allowing the final temperature to be reached in five minutes or less is not suitable because of the breakdown of the structural quality of the resulting product.

The trials carried out with this prototype have also provided a demonstration of the great energy efficiency of this type of cooking. Industrial application of ohmic cooking would allow energy efficiencies greater than 90%. A reduction in energy consumption of 82 to 97% compared to traditional smoke-house cooking could be obtained while meeting the minimal pasteurization specifications necessary for commercial production of a quality product.

To achieve rapid cooking that meets minimal pasteurization criteria, a cooking temperature greater than 75°C is required. The heating phase may be considered to be an instantaneous temperature rise and its pasteurization effect negligible for temperatures not exceeding 80°C. Since the pasteurization effect due to the temperature rise alone is relatively small, much more consideration must be given to the holding time. To achieve the 40 minute pasteurization equivalent, a paste brought to 75°C would have to stay at that temperature for at least 15 minutes, whereas the holding time could be reduced to as little as five minutes at 80°C.

Finally, while industrial scale-up is being pursued, the technical feasibility of this new cooking method for Bologna ham must obviously take into consideration the organoleptic quality obtained by the ohmic method compared to the conventional cooking method. The evaluation of these qualities is the subject of another article (Piette et al. 2004).

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