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OHMIC HEATING BEHAVIOUR OF PROCESSED MEATS

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Background

The benefits of using ohmic heating to cook liquid or particulate foods have been clearly established (Reznick 1996; Sastry and Li, 1996; Sastry and Palaniapan, 1992), leading to a growing number of commercial applications. In contrast, earlier propositions to use ohmic heating in meat processing (see review in De Alwis and Fryer, 1990) have not been put to use by industry, but a recent study shows promising results in processed meat cooking (Peyron, 1996). A comprehensive project was therefore undertaken to evaluate all aspects of ohmic heating applied to processed meat cooking. This particular article reports on the design of an experimental prototype unit to study ohmic cooking of processed meats and on the suitability of meat preparations for ohmic cooking.

Methods

The experimental prototype used in this study (Figure 1) consisted of a 30 cm long Nylon tube (7.5 cm internal diameter; 0.64 cm wall thickness) at both ends of which were inserted 7.5 cm diameter flat circular Titanium electrodes, connected to an electrical power generator designed to provide an alternative current under conditions of either constant intensity (15 A max) or constant potential (240 V max). The unit has a capacity of 1 kg and operates under a fixed pressure, adjustable up to 690 kPa. A series of lateral portholes receives various monitoring devices, such as Teflon-coated thermocouples and optical fibre probes. Variations to this basic concept included use of 1.24 cm thick Nylon or Teflon tube and of a 1 000 V 10 A AC generator.

Two model meat systems were used in the study. The first one (pseudo ham) was prepared by finely homogenizing 85% lean ham trimmings in a basic brine containing water, sodium chloride, sodium nitrite, and sodium erythorbate. The exact composition of the brine was calculated to result in final ham preparations of variable characteristics (salt level 0.7% to 2.3% ; brine/meat ratio 33% to 65%), while maintaining constant the concentrations of sodium nitrite (200 ppm) and erythorbate (500 ppm). The second model system consisted in a finely homogenized meat emulsion of the bologna type, prepared from 85% lean pork trimmings and pork back fat, and formulated to contain 200 ppm sodium nitrite and 500 ppm sodium erythorbate, with either 1% or 2% salt and 20%, 25%, or 30% fat.

A total of 51 cooking experiments were conducted in which pseudo hams or Bologna sausages were cooked at constant intensity (4.5 or 9 A) or constant voltage (64, 76, or 104 V). A separate series of 5 experiments were used to determine the spatial temperature distribution during cooking of fine emulsion sausage, which was obtained through a series of thermocouples inserted to various degrees (transversely) in different longitudinal locations. Electrical conductivity of the products was calculated from the equation $\sigma = (I/V)\cdot(L/A)$, in which I, V, L, and A are the current intensity (A), voltage (V), distance between the electrodes (m) and electrode surface area (m^2), respectively.

Results and discussion

No difference was seen in the cooking experiments or in the resulting products when Teflon was used instead of Nylon as the material for the cooking cell wall, and the cheaper Nylon was used thereafter. The 1.24 cm thick Nylon tubing that was initially used in the cooking cell design resulted in a 15°C temperature gradient within the product mass, between the layer immediately adjacent to the cell wall (colder) and the inside layers, due to heat entrapment within the Nylon itself (result not shown). The problem was partially solved by use of a thinner tubing (0.64 cm), which restricted the gradient extent to 10°C, limited to the 5 mm layer of product along the cell wall (Figure 2). If we neglect this cell wall effect, that will not occur in continuous systems, temperature distribution in the product mass was uniform (CV = 2.2%).

For a given product formulation (standard bologna formula, i.e. 2% salt and 30% fat), the electrical conductivity was found to increase with increasing temperature according to the equation $\sigma = aT + b$ ($R^2 = 0.9948 \pm 0.0026$), with $a = 0.0409 \pm 0.0014\ S\cdot m^{-1}\cdot{}^{\circ}C^{-1}$ and $b = 1.3537 \pm 0.0259\ S\cdot m^{-1}$. This gives a 25°C value of $2.37\ S\cdot m^{-1}$, considerably higher than the values reported for raw meats ($0.08\text{-}1.20\ S\cdot m^{-1}$; Halden *et al.*, 1990; Kim *et al.*, 1996; Mitchell and de Alwis, 1989; Palaniappan and Sastry, 1991; Stirling, 1987) but comparable to that of surimi containing 2% salt ($2.5\ S\cdot m^{-1}$; Yongsawatdigul *et al.*, 1995). Temperature dependency will cause electrical conductivity to increase from $1.56\ S\cdot m^{-1}$ to $4.42\ S\cdot m^{-1}$ during cooking, from beginning (5°C) to end (75°C).

Electrical conductivity was also found to be affected by product composition. Increasing the salt content in pseudo ham (5-10% fat) resulted in an linear increase in conductivity described by the equation $\sigma = 1.1336\ [\%salt] + 1.7776$ ($R^2 = 0.8853$). Conductivity values ranging from $2.91\ S\cdot m^{-1}$ to $4.61\ S\cdot m^{-1}$ can therefore be expected in various commercial hams, corresponding to salt concentrations of 1% to 2.5%, respectively. Similarly, the conductivity of bologna sausage containing 2% salt was found to decrease linearly with increasing fat content, according to the relation $\sigma = -0.0800\ [\%fat] + 3.9166$ ($R^2 = 0.9092$), corresponding to an expected range of $3.12\ S\cdot m^{-1}$ to $1.52\ S\cdot m^{-1}$ in regular bologna sausages (2% salt) containing 10% or 30% fat, respectively.

Typical cooking curves are shown in Figure 3, for a bologna sausage containing 30% fat and 2% salt. Cooking under constant current intensity implies that the voltage is continuously decreased in time to counter increasing product conductivity (Figure 3A). This in turn results in power (P = VI) delivered decreasing over time, which causes the slope of the T = f(time) curve to decrease as cooking proceeds. It may be more practical to cook under constant voltage, in which case current intensity progressively increases due to increased conductivity (Figure 3B), causing the power supplied to increase and cooking to accelerate over time. A third option (not tried) would consist in cooking under constant power, which would cause the cooking rate to stay constant over time until the end of cooking, as reported by Peyron (1996).

Irrespective of the cooking mode selected (constant current or constant voltage), cooking of the 1 kg bologna sausage was completed in 10-11 min, compared to 2.5 h when the same mass of the same emulsion, stuffed into an impermeable casing of the same diameter as that of the cooking cell, was cooked in a smokehouse under a standard commercial cycle (55°C for one hour, 65°C for one hour, and 75°C until core temperature reaches 70°C; 100% RH in all steps), with resulting products being similar in appearance. These results confirm those of Peyron (1996) who reported cooking times of 15 min for liver sausages under ohmic heating, compared to 2 h in an oven. Faster cooking times can even be achieved, if desired. In the present study, the temperature of a 1 kg bologna sausage containing 30% fat and 1% salt, was raised from 10°C to 72°C in 2 min, when submitted to a constant current intensity of 9 A.

Conclusions

The results of the present study indicated that the ionic concentration and general composition typical of processed meats were compatible with ohmic cooking, and that processed meats could be cooked within 5-15 min under conditions of either constant current intensity (3-10 A) or constant voltage (50-150 V). Whether uniform cooking can be achieved in heterogenous (not tested) as well as in homogenous products (this study) remains to be evaluated.

Pertinent literature

De Alwis AAP and PJ Fryer. 1990. The use of direct resistance heating in the food industry. J. Food Eng. 11:3-27; Halden K, AAP de Alwis and PJ Fryer. 1990. Changes in the electrical conductivity of foods during ohmic heating. Int. J. Food Sci. Technol. 25:9-25; Kim HJ, YM Choi, TCS Yang, IA Taub, P Tempest, P Skudder, G Tucker and DL Parrot. 1996. Validation of ohmic heating for quality enhancement of food products. Food Technol. 50(5):253-261; Mitchell FRG and AAP de Alwis. 1989. Electrical conductivity meter for food samples. J. Physics E: Scientific Instruments 22(8):554-556; Palaniappan S and SK Sastry. 1991. Electrical conductivities of selected solid foods during ohmic heating. J. Food Proc. Eng. 14:221-236; Peyron A. 1996. Persectives et développement de nouvelles techniques de cuisson des viandes. Viandes Prod. Carnés.17(6):255-262; Reznick D. 1996. Ohmic heating of fluid foods. Food Technol. 50(5):250-251; Sastry SK and Q Li. 1996. Modeling the ohmic heating of foods. Food Technol. 50(5):246-248; Sastry SK and S Palaniappan. 1992. Ohmic heating of liquid-particle mixtures. Food Technol. 46(12):64-67; Sastry SK and S Salengke. 1998. Ohmic heating of solid-liquid mixtures: a comparison of mathematical models under worst-case heating conditions. J. Food Proc. Eng. 21:441-458; Stirling R. 1987. Ohmic heating

Figure 1: Schematic representation of the ohmic cooking prototype

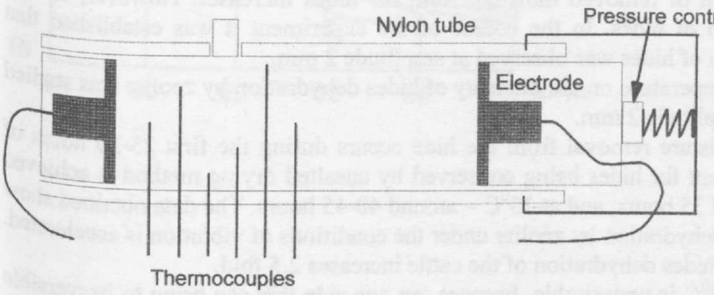

Figure 2:Temperature distibution within the chamber at the end of cooking

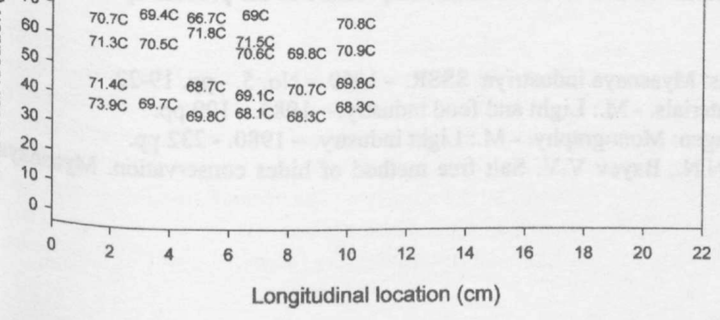

Figure 3: Evolution of voltage, current intensity, and product temperature during ohmic cooking of bologna sausage (30% fat, 2% salt) under constant current or constant voltage