IS THERE A FUTURE FOR OHMIC COOKING IN MEAT PROCESSING ?

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Even though the forced flow of electrical current through meat products (ohmic heating) has been proposed as a cooking method as early as1882 (1), the concept has not led to commercial applications in the meat sector, yet. Earlier attempts to develop an industrial equipment for the continuous ohmic cooking of meat emulsions were abandoned (2, 3), due to the difficulty of maintaining steady state cooking during long periods of times. However, recent successful developments in ohmic cooking of liquid and particulate foods have triggered a new interest in ohmic cooking of solid foods, including processed meats (4, 5, 6), and the results obtained were promising enough to encourage the private sector to investigate again the continuous cooking of meat pastes by ohmic heating (7). The present article reviews our current knowledge on the application of ohmic cooking to processed meats and evaluates the prospects for commercial application of the technology in the near future.

In recent years, three experimental set ups were used to study ohmic heating of processed meats. Mälkki and Jussila (3) used a 3 m long 21 mm ID PTFE tubing through which a commercial fine emulsion was pushed continuously at a speed of 1.0-1.5 $cm \cdot s^{-1}$. Alternative current (50 Hz, 100-200 V, 0.4-1.5 A) was applied in multiple locations, through PVC-covered cylindrical graphite electrodes. Additionally, surface heating was provided by a water-jacketed heat exchanger. Peyron (4) used cooking cells similar to those described by Zuber (8), consisting of open plastic moulds (ca. 20 cm long, 12 cm wide, 10 cm high), at both extremities of which were inserted flat stainless steel electrodes (ca. 10 cm wide, 10 cm high) connected to a 5 kW, 50 Hz AC generator. The moulds could hold ca. 2 kg of raw product and were used to investigate static ohmic cooking of liver paste, country-style pâté, and low-injection cooked ham, prepared according to standard commercial formulations. Finally, the static prototype used in our laboratory consisted of a 30 cm long Nylon tube (7.5 cm ID, 0.64 cm wall thickness) in which a basic raw bologna emulsion or ham paste, containing only meat, water, and curing ingredients (NaCl, $NaNO_2$, sodium erythorbate; no fillers, binders or spices) was pushed with a vacuum stuffer, and at both ends of which were inserted 7.5 cm diameter flat Titanium electrodes, connected to a 60 Hz AC power generator (3.6 or 10 kW).

The amount of energy Q (J) required to heat a mass m (kg) of product is directly related to the product specific heat c_p ($J \cdot kg^{-1} \cdot °C$) and the extent of temperature increase)T (°C), according to the equation $Q = m \cdot c_p \cdot)T$ [eq. 1]. The current intensity I (A) and voltage (V) needed to deliver this energy can be derived from the basic electrical equations $Q = |J|^2 \cdot F^{-1}$ [eq. 2] and $Q = E^2 \cdot F$ [eq. 3], in which J is the current density ($A \cdot m^{-2}$), F is the electrical conductivity ($S \cdot m^{-1}$), and E is the potential gradient ($V \cdot m^{-1}$). Irrespective of the electrical conductivity value, it is always possible, theoretically, to provide a food with enough electrical power to generate the targeted temperature increase)*T*, but this will require using increasingly large current densities or increasingly large potential gradient with increasing or decreasing electrical conductivity values, respectively (see eq. 2 and eq. 3). In reality, various considerations related to safety, cost, and product quality limit the extents of potential gradient and current density that can be used in practice. As a result, ohmic heating is only possible between a certain range of electrical conductivity values (ca. 0.01 $S·m^{-1}$ to 10 $S·m^{-1}$), and it works optimally in the range of 0.1 to 5 $S·m^{-1}$.

In this respect, processed meats are well suited for ohmic cooking, since, given salt and fat contents typical of commercial formulations (5-30% fat, 1-2.5% salt), the *F* values for processed meats always remain between ca. 1 and 7 $S·m^{-1}$ within the range of temperatures normally encountered during cooking. Under these conditions, 1-2 kg of product could be cooked to a core temperature of 70-90°C within 5-20 min in a static unit, when submitted to a power intensity of ca. 500-1000 W, corresponding to heating rates in the 0.05-0.2° $C·s^{-1}$ range (4; Piette, unpublished data). A similar rate, ca. 2.5°$C·s^{-1}$, was achieved in a continuous cooking unit, when a 40-300 W power was delivered between adjacent electrodes (3). All experimental ohmic units mentioned above had low production rates of 7-18 $kg·h^{-1}$ but a much larger prototype (200-400 $kg·h^{-1}$) is already under trial in France (7), and production output is expected to be limited only by unit design.

Nearly all the energy delivered to ohmic cooking units is used to raise product temperature, and energy efficiency values of 90-95% have been reported in the literature (10). Studies involving processed meats, however, have shown considerable heat losses in or through the unit walls (3, 5), or in the air when using open moulds (4), which lowered energy efficiency to values in the 60-70% range (5). Even under these non optimized conditions, though, the specific energy consumption during ohmic cooking of bologna sausage was only 24-30% (210-258 $kJ·kg^{-1}$) of that found in smokehouse cooking (859 $kJ·kg^{-1}$; 5). Therefore considerable energy savings can be expected when heat losses are controlled, through proper unit design (material selection, wall thickness, efficient insulation).

The colour of bologna was not different when sausages were cooked by ohmic heating rather than in a smokehouse (Piette, unpublished data). Also, the flow of electrons through the product did not cause meaningful changes in the concentration of charged ionic species (H_3O^+, see pH column), nor in the overall oxidation status (rH), and it did not induce an acceleration of fat oxidation during storage (TBA after 10 days at 2°C). However, ohmic-cooked sausages were found significantly (P >0.05) softer and noticeably blander than traditional sausages (smokehouse), without being judged inferior by untrained panellists. The softer texture and blander taste of ohmic-cooked fine emulsions observed in our laboratory have not been reported when complete commercial formulations were used, including fillers, binders, and spices (3, 4), indicating that the organoleptic differences caused by very fast cooking are easy to mask, if necessary. Similar results were obtained with coarse emulsion (country style pâté) and whole muscle (low-injection ham) products, suggesting that ohmic cooking can be applied to a wide variety of processed meats, without incurring quality loss.

One peculiar aspect of ohmic heating is that, because of the short time frame involved, cooking can be completed before any significant bactericidal effect is achieved. In effect, pasteurization values $P_{70°C}$ (z =10°C) are virtually null at the time cooking is interrupted, which raises some safety concerns. However, increasing the cooking end-point temperature to 80°C, rather than the usual 70°C, and adding a 5 min holding time prior to cooling are enough to obtain $P_{70°C}$ values of 100 min, equivalent to those found in smokehouse cooking, as already mentioned by Peyron (4).

Even though the prospects of ohmic cooking in meat processing look promising, some problems have been reported which may hinder successful commercial implementation of the technology. Frictions along the cooking unit walls have caused problems in achieving plug flow during continuous cooking in small diameter units (3) and have resulted in rough appearance, but frictions are expected to be a lesser problem in larger diameter units (7). Heat losses along the walls have also been reported, resulting in local undercooking and uneven quality. However, results obtained by Piette *et al.* (5; unreported data) suggest that heat losses can be nearly eliminated by design alterations of the cooking unit. The presence of air bubbles generally causes temperature heterogeneity and may cause arcing at the electrodes but will likely not be harder to control that in the cook-in-the-bag technology. Also, contamination of the products with material coming from stainless steel electrodes has been reported (4), but the problem has apparently been solved by using new material of undisclosed composition for the making of the electrodes (Aussudre, personal communication) and by keeping current density well below 4000 $A \cdot m^2$. Whether all these problems will effectively be solved by better equipment design and process control remains to be seen, but the progress made in the last few years suggests that some practical applications of ohmic cooking in meat processing are likely to be found in the near future.

References

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