

Surface Pasteurization of Raw Poultry Meat by Steam

Arthur I. Morgan, Neil Goldberg, E. Richard Radewonuk and O. Joseph Scullen

U.S. Department of Agriculture Research, Agriculture Research Service, Eastern Regional Research Center,
600 E. Mermaid Lane, Wyndmoor, PA 19038 (U.S.A.)
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*A device to surface pasteurize meat without producing a cooked appearance was built and tested. When inoculated with 10^7 *Listeria innocua* organisms, contamination levels on poultry meat samples were reduced to 10^3 organisms by treatment with steam to 140°C for 50 ms. The extraordinary rapidity of heating was achieved by condensing pure, thermally saturated steam onto the meat surface in the absence of noncondensable gases. Equally rapid surface cooling was then achieved by re-evaporating the condensate on the meat surface back into a vacuum. The best killing was achieved when treatments were repeated. This avoided the shadowing effect of the steel mesh cage which held the meat. The meat surface afforded some protection to the bacteria, compared to a paper surface. The rapidity of the process shows that a practical model could keep up with poultry slaughter line speeds. Such a model, including a sterile wrapping step, is suggested for poultry pieces and cut meats.*

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Introduction

Before slaughter, muscle in normally healthy food animals does not contain microorganisms. The animal's gastro intestinal (GI) tract, however, may harbor toxic microorganisms. Since animal evisceration involves removal of the animal's GI tract, the tract contents may contaminate the meat surface. Also, GI tract contents may crosscontaminate from one carcass to another by successive contact with the hands of workers, with apparatus, or with the contents of various liquid treatment baths into which the meat carcasses may be immersed (1–3). Contaminating microorganisms, if not proteolytic, remain on the surface (4).

Pasteurizing meat surfaces by condensing onto them vapours from various aqueous solutions of organic liquids has been tried (5). Removal of residues proved difficult. Frankfurters were steam surface pasteurized (6). Ionizing radiation killed surface organisms, with only minor changes in the meat (7). The directional nature of this penetrating radiation resulted in overkill on one side to avoid underkill on the other side. Ultraviolet on the other hand was both directional and insufficiently penetrating (8).

The removal of surface contamination from meat has proven to be difficult due to the strong adhesion of microorganisms to the meat surface (9). When hot water wash or spray containing bactericide and surfactant is used, many microorganisms remain alive on the meat (10). This is the case even when the exposure time and bactericide content are more than adequate to sterilize a smooth surface (11). This was also demonstrated with several organic acid solutes and with trisodium phosphate (12).

These results indicate that the failure to pasteurize is due to the water. Water does not reach all the contaminated surfaces because of its liquid nature. Feather, hair or scale follicles are large enough to contain bacteria, but too small to admit a liquid wash or spray. This is because of the high surface tension of aqueous fluids, even when a surfactant is added. An impossibly high water pressure would be needed to overcome the capillary pressure of 40 kPa in a pore just large enough to contain a bacterium (13). This is the consequence of liquid surface tension stretched across a narrow opening.

To be consumer-acceptable, meat must retain its raw appearance, especially its colour and reflectance. This might be described as translucent tan, not opaque white for poultry. This severely limits the use of heat treatments in slaughter houses at present.

Theory

It was desirable to treat the meat surface with steam to kill the microorganisms in place, rather than try to remove them. It may be possible to treat the meat with gas, such as hydrogen peroxide, ozone, or propylene oxide. To avoid residues, however, steam is preferable. Gas treatment is not directional and avoids the surface tension difficulty inherent in liquid treatments. Gases can enter any cavity large enough to contain a bacterium. *Salmonella*, for example, are short, straight rods, 0.7 μm in thickness and 4 μm long, whereas gas molecules are about 2×10^{-4} μm in diameter. Inactivation of the most sensitive vital enzyme is enough to kill bacteria. While the enzymes may not be

on the surface of the bacterium, the size of any bacterium is such that the enzyme must be very close to an exposed surface, unless the bacteria are clumped. Typically, the heat of activation for these nearly reversible reactions is 2–12 kcal/(g.mol). On the other hand, the heat of activation for irreversible muscle cooking is 50–100 kcal/(g.mol) (14).

Only micrograms of enzyme need be inactivated for microbe killing, contrasted with grams of muscle which are denatured for meat cooking. For a square centimetre of surface contaminated with 100 bacteria, 15 million times as much heat is needed to cook the surface to a depth equal to the length of a bacterium, compared to the heat needed to kill all the bacteria.

Bacteria are assumed to be exposed on the surface, whereas much of the muscle which must be denatured for a cooked appearance lies very slightly below the surface. The rate of heating below the surface is proportional to the rather low heat conductivity of the meat. Even convective heat transfer cannot occur there because of the cellular nature of the meat. Heat conduction in the body of the meat is thus very much slower than surface heating by steam condensation. So, if the heating rates of meat and microorganisms were equal, the bacteria would die earlier than the meat would cook. For these reasons, it is possible to surface pasteurize meat without cooking it.

Gas condensation velocity is reduced in cavities of diameter less than the mean free path of the gas. Mean free path decreases with increasing gas density. For 140 °C saturated steam, the mean free path of the steam molecule is 0.4 µm. This is about half the diameter of the smallest cavity capable of containing a *Salmonella*. Therefore, steam can quickly reach all organisms on the meat surface.

Although steam may reach and kill each surface bacterium, it usually does not do so before the sub-surface of the meat has received a heat dose sufficient for cooking. To accomplish surface treatment without significant cooking, the steam must reach the surface and condense extraordinarily rapidly, and re-evaporate and leave equally rapidly.

A gas approaches a surface in one of two possible modes, flow or diffusion. Flow is very rapid, and motivated by a pressure gradient. Diffusion is much slower and motivated by a concentration gradient of the gas through other gases (15).

During steam treatment, air, or any other noncondensable gas present, is concentrated near the surface because it is pushed up to the surface by the inrush of condensing steam. This air quickly forms a layer near the surface (16), and additional steam must then diffuse through this layer, since it cannot flow through it. The time taken for a killing dose of steam to reach the target microorganisms is therefore strongly dependent on the quantity of noncondensable gases which lie between the incoming steam and the meat surface. The magnitude of this phenomenon was first measured during observation of steam injection heating (17).

These interfering noncondensable gases can arise from three sources; gases which were around the meat when

it was enclosed in its treatment chamber; gases entering with the treatment steam; and gases which have been desorbed by heat from the meat or other surfaces. It is necessary to minimize each of these three sources of interfering noncondensable gas to achieve quick treatment.

Methods

The air surrounding the meat was reduced by exposing the meat to a vacuum at 2 kPa. To achieve this, the meat was inserted in a rotatable chamber (Fig. 1). This chamber was then rotated to the opening of a vacuum receiver.

To reduce noncondensable gases in the treatment steam, pure feed water, which had been degassed by boiling for 60 min, was used in an electric steam generator. Superheated steam is equivalent to noncondensable gas, since it must be cooled by convection before condensing. Therefore, to avoid superheat, the steam generator was connected to the treatment chamber by 50 mm diameter ducts, no longer than 1000 mm.

To reduce the noncondensable gases desorbed from the meat and chamber surfaces, it was necessary to flush the meat in its evacuated treatment chamber with air-free low temperature steam. To do this, the treatment chamber was rotated from the vacuum receiver opening to the steam treatment opening, through an arc, at the midpoint of which there were 1 mm wide openings to both the vacuum and steam supply simultaneously. The chamber was shaped to promote good circulation of the flushing gas around the meat. To further reduce gas evolution from the meat, any water wash used on the meat just prior to surface pasteurization was free of chlorine.

After treatment, the steam and its delivered heat was

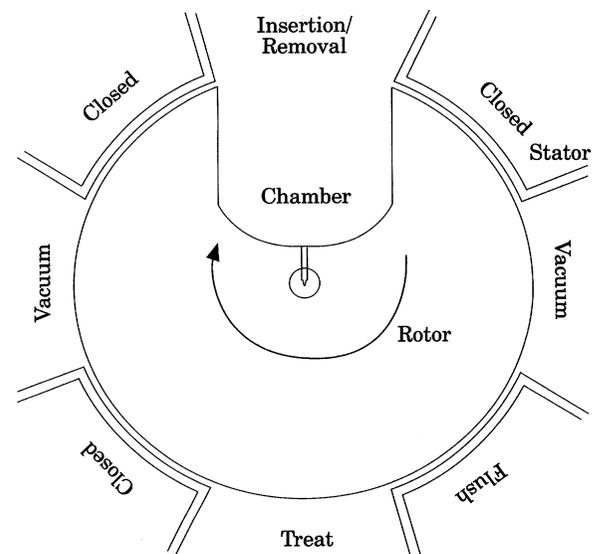


Fig. 1 Schematic representation of the surface pasteurization process

rapidly removed by rotating the chamber to a wide opening into a vacuum, to cool the meat surface nearly to the temperature at which it began the treatment. This was a consequence of re-evaporating all the condensate formed on the meat surface by the saturated treatment steam. In this way, almost the same quantity of heat is removed as had been added. The result was that the surface had been uniformly heated, and then uniformly cooled nearly to its original temperature, all within milliseconds, without much heat reaching the subsurface of the meat. For these reasons, the device could be called a heat lender (18).

Equipment

Figure 2 shows the steps carried out in the surface pasteurisation process. Figure 1 shows the principle of the test device. The device consisted of a stainless steel stator containing a stainless steel cylindrical rotor. The rotor was 150 mm long and 150 mm in diameter. A programmable servo-drive motor (Allen Bradley, Milwaukee) was provided to turn the rotor rapidly around its horizontal axis, stopping at precisely determined angular positions. The servo-drive exerted 50 J of torque, so that high acceleration and braking rates were used. On opposite sides of the rotor, two treatment chambers were milled into the cylindrical surface, each oval in the tangential plane, 25 mm wide along the curved surface, 75 mm long across the rotor surface, and 25 mm deep. The chambers had rounded bottoms.

Each half of the stator was provided, clockwise, with an opening to air, then to vacuum, then to steam, then again to vacuum, and back to air. The series was repeated on the opposite side, so that the radial forces on the rotor were balanced. Each of the stator openings were connected to the rotor through PEEK (poly-

etheretherketone) oval seals which were held against the rotor by compressed O-rings in the stator.

The angular displacements between stator openings relative to the angle subtended by the top of the rotor chamber were such that each opening was closed off from the next during rotation. However, the displacement between the first vacuum and the steam, on each side, was less than the others. This provided openings 1 mm wide at maximum from steam into the chamber, and from the chamber out into vacuum, as the chamber passed from vacuum to steam, and caused a momentary flush of steam through the chamber and out into vacuum.

A 200 L tank with electric heating was provided as a steam generator. Adequate steam venting and degassed feed water were used. Another 200 L tank served as vacuum receiver. It contained a refrigerated surface condenser. A two stage piston pump evacuated the receiver to 2 kPa. Both tanks were connected to the stator through short lengths of 50 mm diameter tubing.

Meat

Chicken meat was cut from breast muscles of broilers purchased from a market. Small meat samples, about 5 g, were cut to 10 mm by 10 mm, 50 mm long, with one side being the intact epimysium.

Cooking of the samples was judged subjectively. The colour and brightness changes in cooking chicken muscle were unmistakable. The L value from a Hunter Color Meter correlated well with the subjective analysis for cooking, though parts of the samples which first showed signs of cooking were too small for instrumental analysis.

Microbiology

The meat samples were inoculated on the epimysial surface with a total of 10^7 freshly grown *Listeria innocua*. The fresh culture was dripped onto the meat, which was then allowed to dry inside a biological hood. *L. innocua*, SA3-VT, a nonpathogenic substitute for *L. monocytogenes*, had been grown in 100 mL brain-heart infusion (Diffco, Detroit) with 300 mg glucose at 28 °C for 18–24 h.

Immediately after treatment, the meat sample was homogenized in a stomacher bag (Seward Medical, London) with 9.9 mL 1 g/L peptone at 24 °C. After homogenizing, dilutions in peptone were plated spirally (Spiral Systems Instruments, Cincinnati) onto tryptose agar (Diffco, Detroit) and incubated for 24 h at 37 °C before colony forming units (cfu) were counted with a Bacteria Colony Counter, model 500A. Inoculated and uninoculated untreated controls were counted the same way. Inoculated samples which had been cooked (140 °C for 2 s) were also counted.

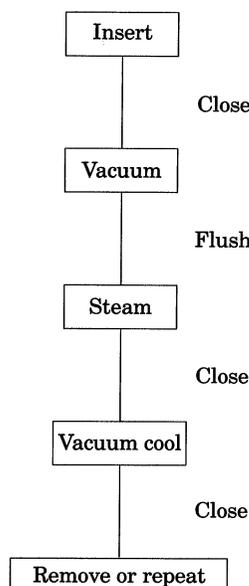


Fig. 2 Steps involved in the surface pasteurisation process

Treatments

The inoculated meat samples were inserted into stainless steel mesh cylinders. The cylinders were restrained within one of the test chambers of the rotor and immediately treated.

The meat was loose enough within the cylinder to permit flush gas flow on all sides. Also, the chamber accelerated in such a way, relative to gravity, that the mesh did not continuously obscure any one part of the meat surface from the gas when the treatment was repeated several times.

The exposure times have been calculated from nominal rotor velocity and acceleration settings. When the treatments were repeated, with cooling after each heating, times given are for a single heating event.

Results

The limits of heat dose before cooking start are shown in **Table 1**. These are the nominal exposure times in air-free thermally saturated steam at various temperatures when a cooked appearance just appears on thin edges and exposed filaments of the meat sample. For comparison, the time to achieve a cooked appearance in 100 °C water is about 1000 ms.

Table 2 shows the effects of time and temperature on the reduction in log counts of colony forming units between the untreated, inoculated sample and the treated, inoculated sample. The count of the inoculated untreated controls were always about 10⁷ cfu/mL. Uninoculated controls always showed less than 10² cfu/mL. Each value in **Table 2** is the mean of three meat samples treated. The standard deviation of the mean

Table 1 Time for cooking to begin on broiler meat pieces at various temperatures

Temperature (°C)	Time (ms)
100	1000
113	330
119	140
128	110
132	100
143	90
143	90
150	80

Table 2 Log reductions of *L. innocua* on chicken after treatments

Cycles	Steam temperature (°C)	Duration of steam per cycle (ms)	Log reduction	Final log count
40	139	52	3.9	2.7
10	138	52	3.4	3.2
20	126	124	3.2	3.4
18	129	52	3.0	3.6
40	139	103	3.0	3.6
40	130	103	2.8	3.8

was 0.3 log count. The deviation did not show a dependence on log kill.

When filter paper strips were inoculated and treated for 60 ms at 125 °C, over 6.3 log reduction was achieved. Under the same conditions, only 3.0 log reduction could be expected on chicken meat. This demonstrates the protective effect the meat surface has on the survival of *L. innocua*.

The counts, even after a good steam treatment, are very high for *Listeria* on poultry meat in commerce. The huge inoculation rates are used to calibrate treatments on pieces of meat so small that most would be free of wild surface organisms, were they used directly from the birds. The proportional kills found are probably inaccurate if applied to most uninoculated meat. Presumably they are appropriate for comparisons between steam treatments.

Conclusion

Killing surface bacteria on poultry with steam without cooking the underlying meat is possible. Process design must accommodate the marked protective effect the meat surface provides to bacteria. It is inherently a rapid process which could keep up with the modern poultry slaughter lines. It appears that a single machine could be designed to handle a full speed poultry line. Scale-up to whole birds would require a 4 L chamber rotating around its axis. However, a different scale-up choice could be made. Since the output of the pasteurizer should be wrapped anyway, the pasteurizer could be designed to operate on cut pieces, rather than on whole birds. For this choice, a 300 mm rotor, 300 mm wide would be used. Treatment chambers in such a rotor could be 1 L in volume, and shallow. The servo-drive, boiler and vacuum systems could all be correspondingly smaller.

A practical machine would include two wrapping steps which will take advantage of the vacuum system. Atmospheric pressure would push sterile wrap into the chamber as a liner before the meat is inserted. When the chamber is returned to air, a covering wrap would be pushed by air onto the meat before the nonsterile air could touch it. Compressed air entering below the liner at the removal position would eject the final product. This would preclude a sterile space requirement.

References

- 1 DICKSON, J.S. Transfer of *L. monocytogenes* and *S. typhimurium* between beef tissue surfaces. *Journal of Food Protection*, **53**, 51–56 (1990)
- 2 THOMAS, C.J. AND McMEEKIN, T.A. Effect of water uptake by poultry on contamination by bacteria. *Journal of Food Protection*, **47**, 398–404 (1984)
- 3 BAILEY, J.S., COX, N.A. AND BLANKENSHIP, L.C. Persistence and spread of external *Salmonella* during broiler production. *Poultry Science*, **69**, 154–158 (1990)
- 4 GILL, C.O. AND PENNEY, N. Penetration of bacteria into meat. *Applied and Environmental Microbiology*, **33**, 1284–1286 (1977)

- 5 KLOSE, A. A. AND BAYNE, H. G. Experimental approaches to poultry meat surface pasteurization by condensing vapors. *Poultry Science*, **49**, 504–512 (1970)
- 6 CYGNAROWICZ-PROVOST, M., WHITING, R. C. AND CRAIG, J. C. Steam surface pasteurization of beef frankfurters. *Journal of Food Science*, **59**, 1–5 (1994)
- 7 THAYER, D. W., CHRISTOPHER, J. P., CAMPBELL, L. A., RONNING, D. C., DAHLGREN, R. R., THOMSON, G. M. AND WIERBICKI, E. Studies of irradiation-sterilized chicken. *Journal of Food Protection*, **50**, 278–288 (1986)
- 8 KAWAGUCHI, K. AND TANAKA, Y. Sterilization of vacuum packaged raw meat by ultraviolet. *United States Patent*, 4,983,411 (1991)
- 9 LILLARD, H. S. Impact of commercial processing procedures on bacterial contamination of broiler carcasses. *Journal of Food Protection*, **53**, 202–205 (1990)
- 10 JAMES, W. O., BREWER, R. L. AND PRUCHA, J. C. Effects of chlorination on bacteriologic profile of raw chicken carcasses. *Journal of the American Veterinary Association*, **200**, 60–69 (1992)
- 11 HURST, W. D. Method for sanitizing poultry carcasses utilizing ozonated water. *United States Patent* 4,849,237 (1989)
- 12 LILLARD, H. S. Effect of TSP on *Salmonellae* attached to chicken skin. *Journal of Food Protection*, **57**, 465–468 (1994)
- 13 GLADSTONE, S. The liquid state. In: *Physical Chemistry*. New York: D. Van Nostrand (1948)
- 14 HARPER, J. C. Dehydration. In: *Elements of Food Engineering*. Westport, CT: AVI Press. (1976)
- 15 MINKOWYCZ, M. AND SPARROW, A. Condensation rates of pure versus impure vapors. *International Journal of Heat and Mass Transfer*, **9**, 1125–1134 (1966)
- 16 PERRY, R. H. AND CHILTON, C. H. Heat transmission. In: *Chemical Engineers Handbook*, 5th Edn. New York: McGraw Hill (1974)
- 17 MORGAN, A. I. AND CARLSON, R. A. Steam injection heating. *Industrial Engineering Chemistry*, **52**, 219–225 (1960)
- 18 MORGAN, A. I. Method and apparatus for treating and packaging raw meat. *United States Patent* 5,281,428 (1994)

Osmotic Dehydration Kinetics of Pineapple Wedges using Palm Sugar

Parjoko, M. Shafiur Rahman*, Ken A. Buckle and Conrad O. Perera

Parjoko, K. A. Buckle: Department of Food Science and Technology, University of New South Wales, Sydney, NSW 2052 (Australia)

M.S. Rahman, C. O. Perera: Horticulture and Food Research Institute of NZ Ltd., Private Bag 92 169, Mt. Albert, Auckland (New Zealand)

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Osmotic dehydration kinetics of pineapple wedges was studied using palm sugar at different syrup concentration and temperature. Equilibrium kinetics were presented by defining equilibrium constants and nonequilibrium period of water loss and solid gain followed the model based on mass balance and zero order reaction kinetics. At constant temperature, the rate constants for both water and solids increased with increase in syrup concentration. At constant syrup concentration, the rate constants of water increased and the rate constants of solid decreased with the increase of temperature. Temperature had much more effect at high syrup concentration.

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Introduction

Osmotic dehydration of foods has gained attention recently due to its potential application in the food processing industry. Osmotic dehydration generally will not give a product of sufficiently low moisture content to be considered shelf-stable. Consequently, the osmosed (sugar-infused) product should be further processed (generally by air-, freeze- or vacuum-drying or pasteurization) to obtain a shelf-stable product or used as a pretreatment for canning, freezing or minimal processing. Many investigators recommended that the quality (colour, flavour and texture) of air-, freeze- or vacuum-dried fruits and vegetables could be improved by a prior osmotic step. Rahman (3), Torreggiani (4) and Raoult-Wack (5) reviewed the merits of osmotic dehydration for improvement of product quality and process efficiency.

Osmotic dehydration is the process of water removal by immersion of a water-containing cellular solid in a concentrated aqueous solution. The difference in chemical potential between fruit and syrup causes water removal. If the membrane of the food is perfectly semipermeable, solute is unable to diffuse through the membrane into the cells. However, it is difficult to obtain a perfect semipermeable membrane in food systems due to their complex internal structure, and there is always some solute diffusion into the food and leaching out of the food's own solutes. Thus, mass transport in osmotic dehydration is actually a combination of a simultaneous water and solute transfer

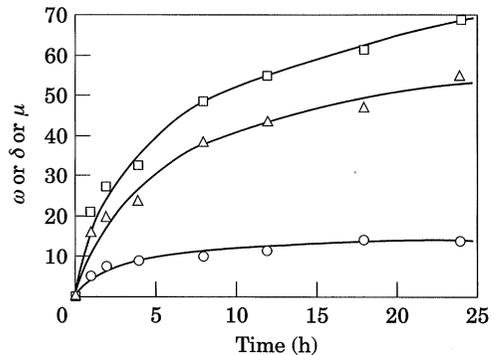


Fig. 1 Water loss, ω , (\square), weight loss, μ , (\triangle) and solid gain, δ , (\circ) of pineapple wedges in palm sugar at 546 g/kg syrup and 30°C

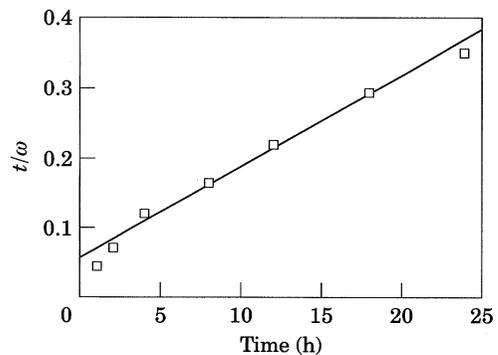


Fig. 2 Plot of (t/ω) vs. t for osmotic dehydration of pineapple at 546 g/kg syrup and 30°C

*To whom correspondence should be addressed.