

# Time and Temperature Controls

STEPHEN G. CAMPANO\* and PARKER W. HALL, JR.

## Introduction

During the manufacture of processed meat products, considerable attention should be placed on the relationship between time and temperature. This relationship is of concern not only during thermal processing, but should also be taken into account during all stages of manufacture, including heating, holding, and cooling. Any number of time and temperature combinations exist during the processing of meat products that affect the quality of the finished food. These quality criteria include the microbiological safety and shelf-life of the product as well as the organoleptic parameters of texture, flavor, and juiciness. Control and optimization of time and temperature is influenced by many factors including, but not limited to, raw material selection, nonmeat ingredients, processing equipment, and packaging technology.

In discussing the topic of time and temperature control, it is notable to comment on the efforts of the canned food industry. For many years, this food industry segment has employed mathematics and heat transfer technology to develop and optimize processes necessary to achieve desired finished product quality attributes (Ball and Olson, 1957). These efforts have led to the understanding of thermal death curves of selected pathogenic microorganisms. The fate of these microorganisms is largely dependent upon the combined time and temperature of the heating and cooling process. However, several fundamental differences exist between the processing of canned foods versus most processed meat products. In general, canning affords the processor identical product geometry combined with retort conditions. These standard conditions facilitate the development and optimization of a time/temperature process usually designed to achieve commercial sterility.

Processed meat products often do not possess or maintain identical geometry. In addition, they may be exposed to several different time and temperature combinations through the manufacturing process, none of which are likely to reach

those encountered during retort processing. In many cases, conditions necessary to produce commercial sterility in processed meat products would alter the traditional organoleptic properties to a point where the product may no longer be edible. In addition, processing techniques such as least cost formulating may alter the thermal properties of the product through modifications in raw material mix and proximate composition.

## Factors Influencing Time/Temperature Determination

The addition of certain nonmeat ingredients can influence the thermal properties and thermal requirements of meat products. For example, sodium chloride (NaCl) has been shown to alter the thermal properties of meat products by decreasing the denaturation temperature of muscle proteins (Martens and Vold, 1976; Barbut and Findley, 1991). The addition of starch to meat loaves has been shown to modify thermal conductivity (Skjöldebrand and Hallström, 1980). Starches are included in many processed meat products, primarily for their ability to control water movement. The influence of time and temperature on the viscosity of several native starches in a starch-water system is demonstrated in Figure 1. Certain native starches may require gelatinization (loss of birefringence) temperatures higher than the traditional finished product temperatures encountered during thermal processing of meat products. Modified starches have been developed and designed to reach maximum functionality at reduced temperatures. In general, slow heating patterns create more even heat transfer resulting in a greater degree of starch gelatinization vs. rapid cooking. The behavior of starch in complex food systems is further influenced by pH, total solids, proximate composition and availability of free water (Table 1). For example, starches incorporated into meat products through brines or pickling solutions will require higher gelatinization temperatures.

The inclusion of nonmeat proteins also influences the thermal performance of meat products. A simple example can be demonstrated by examining the effect of cooking time on the final internal temperature of beef patties formulated with varying levels of extension with textured soy protein concentrate. Patties formulated to similar protein ( $15.2 \pm .2\%$ ), fat ( $25.3 \pm .3\%$ ), and moisture levels ( $58.2 \pm .3\%$ ),

\*Stephen G. Campano, Central Soya Company, Inc., Fort Wayne, Indiana.

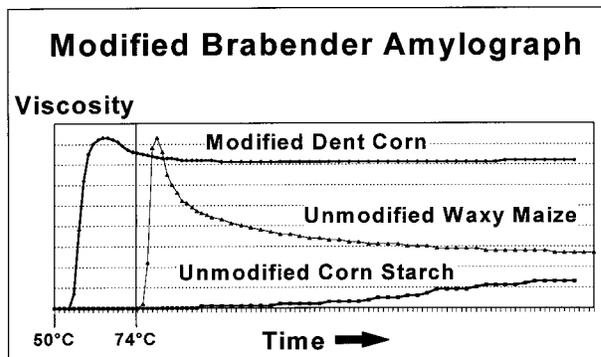
*Reciprocal Meat Conference Proceedings, Volume 50, 1997.*

**TABLE 1. The Effect of Other Ingredients on the Functionality of Food Starch.**

<b>Acid</b>	Disrupts hydrogen bonding; Cleaves starch molecule	Accelerates gelatinization and viscosity breakdown
<b>Total Solids</b>	Compete for available water	Delay gelatinization and viscosity development;
Sugar		Bind water and contribute viscosity
Salt		
Gums		
Protein		
<b>Protein</b>	May coat starch granule and delay hydration	Delay gelatinization and viscosity development
<b>Fat</b>		
<b>Water</b>	Required for hydration	Balance starch; water ratio

Courtesy of Cerestar USA, Hammond, Indiana.

**FIGURE 1.**



Courtesy of Grain Processing Corporation, Muscatine, Iowa.

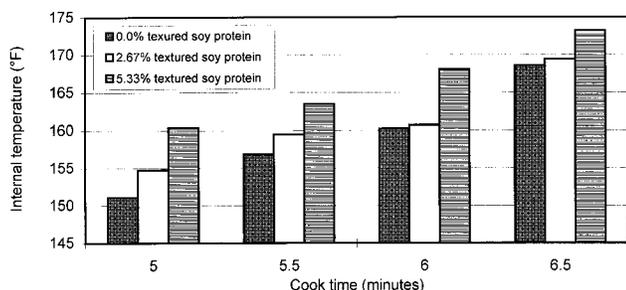
containing 0.0%, 9.4%, or 18.9%, hydrated soy protein concentrate were formed using a Formax<sup>®</sup> (Model F6, Mokena, IL) machine to a thickness of 0.95 cm and weight of 90 grams. Patties were cooked from a frozen (-14°C) state on a flat griddle at 163°C (AMSA, 1995) for 5, 5.5, 6, or 6.5 minutes. The maximum internal temperature was recorded near the geometric center of each patty using a 1.6 mm (0.063 in) diameter type T (copper/constantan) thermocouple. The data in Figure 2 indicate that as the level of extension increased, the internal product temperature increased when thermally processed under similar time/temperature conditions.

The configuration of forming equipment also influences thermal performance of beef patties. Beef patties (formulated as stated previously) were formed using either a "standard fill" (SF) or "Tender-Form"<sup>™</sup> (TF) configuration on a Formax F6. The standard fill results in a laminar or layered effect while the Tender-Form creates a columnar orientation of the

beef patty fibers. Figure 3 shows the internal temperature of SF vs. TF beef patties cooked as previously stated. Under these conditions, it is evident that the Tender-Form product reached a higher internal temperature for a specific time.

Heat and mass transfer of multi-component meat systems is complex and beyond the scope of this discussion. However, certain basic principles are noteworthy. Thermal conductivity of meat systems is largely dependent on the structure of the different components—especially water, and the apparent density of the food product (Perez and Calvelo, 1984). Parameters such as temperature, air velocity, and humidity will influence heat transfer and the finished quality of meat products (Hanson, 1990; Holtz, et al. 1984; Monagle, et al. 1974). Accordingly, it is important to consider the formulation variables of ingredients and ingredient combinations as well as the mechanical systems involved during manufacture when developing thermal processing

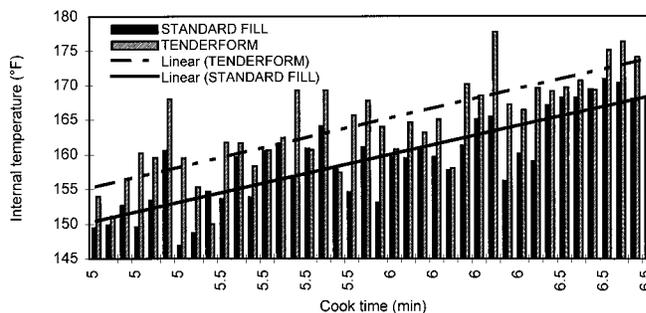
**FIGURE 2.**



Cook time vs. internal temperature of beef patties<sup>1</sup> manufactured with varying levels of textured soy protein concentrate.

<sup>1</sup>Beef patties formulated to contain 15.3% total protein, 25.0% total fat, and 58.0% total moisture with 0.0%, 9.4% or 18.9% hydrated textured soy protein concentrate. Patties were cooked on a flat griddle at a temperature of 325°F (162.8°C). n = 16 (5, 6.5 min); n = 24 (5.5, 6 min).

**FIGURE 3.**



Internal temperature vs. cook time for beef patties<sup>1</sup> formed with Formax Standard Fill or Tenderform Apparatus.

<sup>1</sup>Beef patties formulated to contain 15.3% total protein, 25.0% total fat, and 58.0% total moisture with 0.0%, 9.4%, 18.9% or 28.8% hydrated textured soy protein concentrate. Patties were cooked on a flat griddle at a temperature of 325°F (162.8°C).

**TABLE 2. Heat Treatment for the Destruction of Trichina in Pork and Products Containing Pork.**

Minimum internal temperature		Minimum time
Degrees Fahrenheit	Degrees Centigrade	Minutes
120	49.0	21 hours
122	50.0	9.5 hours
124	51.1	4.5 hours
126	52.2	2 hours
128	53.4	1 hour
130	54.5	30 minutes
132	55.6	15 minutes
134	56.7	6 minutes
136	57.8	3 minutes
138	58.9	2 minutes
140	60.0	1 minute
142	61.1	1 minute
144	62.2	instantly

Adapted from 9 CFR 318.10 (1994).

**TABLE 3. Time/Temperature Combination for Cooked Beef, Roast Beef, and Cooked Corned Beef.**

Minimum internal temperature		Minimum processing time after minimum temperature is reached
Degrees Fahrenheit	Degrees Centigrade	Minutes
130	54.5	121
131	55.0	97
132	55.6	77
133	56.1	62
134	56.7	47
135	57.2	37
136	57.8	32
137	58.4	24
138	58.9	19
139	59.5	15
140	60.0	12
141	61.1	10
142	61.7	8
143	61.7	6
144	62.2	5
145	62.8	instantly

Adapted from 9 CFR 318.7 (1994).

time and temperature controls. Surveillance of the time and temperature conditions encountered throughout the manufacture of processed meat products should be an integral part of good manufacturing practice in order to assure the desired quality outcome.

### Regulatory Issues

The USDA Food Safety and Inspection Service has published a number of requirements and recommendations in the form of regulations, directives, and policy memoranda for time and temperature control of cooked meat and poultry products. A compilation of issuances on cooked meat and poultry products temperatures is summarized and referenced in FSIS Directive 7370.2 (USDA, 1995). Time/temperature guidelines for cooling heated products is outlined in FSIS Directive 7110.3 (USDA, 1989). The prescribed treatment for destruction of trichina in pork and products containing pork is outlined in 9 CFR 318.10.

FSIS involvement in establishing these guidelines is generally related to food safety issues. The USDA's Economic Research Service recently updated the estimated foodborne disease costs for seven foodborne pathogens, including *Campylobacter jejuni*, *Clostridium perfringens*, *Escherichia coli* O157:H7, *Listeria monocytogenes*, *Salmonella*, *Staphylococcus aureus*, and *Toxoplasma gondii*. Estimates indicate that these pathogens account for 3,300,000 to 12,300,000 cases of foodborne illness and 1,900 to 3,900 deaths annually, accounting for as much as \$34.9 billion in medical expenses, lost production, and loss of life (Buzby and Roberts, 1997). Current regulations (9 CFR 318.7, 318.23, and 381.150) prescribe specific steps to ensure that harmful bac-

teria are killed, growth of spore-forming bacteria is controlled, and recontamination of the product is prevented.

The most detailed time and temperature regulations resulted from a number of salmonella food poisoning outbreaks. In 1977, cooking requirements were established for cooked beef and roast beef as an "emergency measure" to prevent further outbreaks. After several additional incidents involving salmonellosis in 1981, new interim final rules were established to reorganize, clarify, and strengthen the cooking, storage, and handling requirements of these products. In addition, surveillance samples of cooked corned beef were found positive for the presence of salmonellae, which prompted FSIS to incorporate cooked corned beef into this rule. The basis of the regulation involves specifications for time and temperature control during heating and cooling (Table 2), relative humidity control, the requirements for monitoring equipment, written procedures, production dating, product identification, product sizing, and physical separation of raw and cooked product (USDA, 1982). These time and temperature specifications for thermal processing are supported by the results established by Goodfellow and Brown (1978). The interim final rule was amended in 1983, modifying the chilling, size control, and humidity requirements for thermal processing, and published as a final rule (USDA, 1983).

Although this regulation is explicit, cooked beef manufacturers retain a degree of flexibility in thermal processing that can impact certain finished product quality attributes. For example, an important quality characteristic for rare roast beef is uniformity of color. Often, a processor would consider employing a "Delta T" process to achieve this result. The principle behind this cooking process is to maintain a

**TABLE 4. Permitted Heat-Processing Temperature/Time Combinations for Fully-Cooked Patties.**

Minimum internal temperature at the center of each patty		Minimum holding time after maximum temperature is reached	
Degrees Fahrenheit	Degrees Centigrade	Minutes	Seconds
151	66.1	0.68	41
152	66.7	.54	32
153	67.2	.43	26
154	67.8	.34	20
155	68.3	.27	16
156	68.9	.22	13
157 (and up)	69.4	.17	10

*Adapted from 9 CFR 318.23 (1994).*

constant temperature differential between the product core and the dry or wet bulb temperature of the cooking chamber. An alternative method would be to begin the thermal process at a relatively high temperature and gradually decrease the temperature of the cooking chamber as the product core temperature increases.

Certain fully cooked, uncured meat patties, including hamburgers, Salisbury steaks, battered and breaded chopped veal steaks, beef patties, and pork sausage patties are also required by FSIS to be thermally processed according to specific time/temperature guidelines (9 CFR, 318.23, 1994) in order to reduce the risk of food-borne illness (Table 4). Although much of the recent attention has been focused primarily on the occurrence of food-borne disease outbreaks caused by *E. coli* O157:H7 in undercooked ground beef from foodservice establishments, at least one outbreak has been linked to precooked hamburger patties (USDA, 1993a). The proportion of precooked beef patties is small compared to the total production of ground beef. However, FSIS concluded that an outbreak of food-borne illness from *E. coli* is statistically greater for heat-treated beef patties than for raw ground beef (USDA, 1993a). Although the regulation does not account for variations in product formula, e.g., fat level, salt content, additives, etc., research suggests that reduced

fat and added salt provides an additional safety margin for the thermal destruction of *E. coli* in certain ground meat products (Ahmed, et al. 1995).

FSIS Directive 7370.1 (USDA, 1993b) provides instructions for verifying internal temperature and holding time of meat patties. The directive is primarily intended to provide FSIS inspection personnel with a clear set of guidelines when performing the appropriate time/temperature task. The directive indicates that only thermocouple probes of small diameter (0.063 in., 1.6 mm) be used to verify internal temperature. The probe should be inserted from the side of a single patty (never stacked), placing the sensitive area as close to the geometric center of the patty as possible. After insertion of the probe, “a couple of seconds” should be allowed for equilibration, upon which time the minimum internal temperature of the patty should be recorded.

These instructions appear simple enough, but anyone who has attempted this task probably recognizes the difficulty involved in attaining both precision and accuracy. FSIS admits that the temperature gradient at the surface of a patty can be >200°F and <140°F in the interior, which essentially indicates that a small error in approximating the geometric center of a patty can result in a relatively large error in temperature determination. In addition, thermocouples have

**TABLE 5. Products Requiring a Heat Process to Ensure Safety of the Finished Product.**

Product Description	Temperature Requirement	Labeling Requirement	MPI Reference <sup>1</sup>
Partially-Cooked Patties	minimum 140°F internal	“Partially cooked: For safety, cook until well done (Internal meat temperature 160°F)”	318.23 (b) (1) (ii)
Char-Marked Patties	maximum 70°F internal	“Uncooked, char-marked: For safety, cook until well done (Internal meat temperature 160°F)”	318.23 (b) (1) (iii)
Poultry Breakfast Strips	140°F internal	“Partially cooked: For safety, cook until well done”, with detailed cooking instructions	381.150 (b)
Cooked, Uncured Poultry	at least 160°F internal temperature		381.150 (b)
Cooked, Cured and Smoked Poultry	at least 155°F internal temperature		381.150 (b)

<sup>1</sup>*Meat and Poultry Inspection Regulations, 9 CFR (1994).*

characteristic response times (time constants), usually in the 2-3 second range for probes of 0.063 inch (1.6 mm) diameter. Five time constants are required for probes to reach 99% of the final reading, i.e., a probe with a 3 second response time reaches its final reading in approximately 15 seconds (Cole-Parmer Instrument Company, Vernon Hills, IL, 1997). This response time raises a question as to the accuracy of the reading when a probe is allowed to equilibrate in the center of a patty for only a couple of seconds. Conversely, if the probe is allowed to reach its final reading after approximately 10-15 seconds, and the temperature recorded at this point, one must be concerned with any cooling effect that might have occurred.

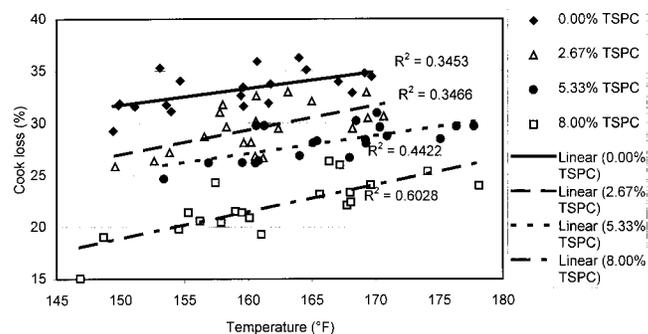
### An Alternative Approach

Monitoring the internal temperature of meat patties with an accurate temperature recording device is seemingly more appropriate than visual appraisal. Recent studies indicate that beef patties cooked to 66°C (151°F) could appear equally as brown in color as patties cooked to 71°C (160°F) (Hague, et al. 1994). Conversely, beef patties cooked to an internal temperature of 71°C can exhibit an internal color indicative of undercooked product (Mendenhall, 1989). Visual cooked meat color may be influenced by pH (Schmidt and Trout, 1984, Trout, 1989, Mendenhall, 1989, Brewer and Novakofski, 1997), additives such as salt and phosphate (Trout, 1989), and texture-modifying agents (Trout, et al. 1992a). With this in mind, food-service establishments and consumers relying on visual appraisal may be at risk of misinterpretation of doneness. The issue of premature browning recently prompted FSIS to alert consumers that the color of meat is no longer considered a reliable indicator of ground beef safety, and advised consumers to use a meat thermometer to verify that hamburger is safe to eat (FSIS, 1997). Cooking to a specific time correlated highly with endpoint temperature (Hague, et al. 1994), but many other considerations including initial state (fresh vs. frozen), cookery method, cooking temperature, patty size (Cross and Berry, 1980), and fat level (Trout, et al. 1992b) must be taken into account.

The American Society for Testing and Materials (ASTM) Standard Test Method for Performance of Griddles (ASTM, 1995), states that research conducted at Pacific Gas and Electric Company (San Ramon, CA) determined that a linear relationship exists between the final internal temperature of cooked hamburger patties (20 ± 2% fat and 58-62% moisture) and the percent weight loss incurred during cooking. If this linear relationship holds true, determination of internal temperature could be simplified and many of the previously mentioned factors influencing cooked meat color would be minimized. In addition, this method may redact the determination of internal temperature for pre-cooked meat patties.

Obviously, verification of this theory necessitates the development of standard curves for specific product formulations. A preliminary study was conducted to determine the efficacy of this method using a range of beef patty formulas similar to those outlined above. Two groups of 2 patties each

FIGURE 4.



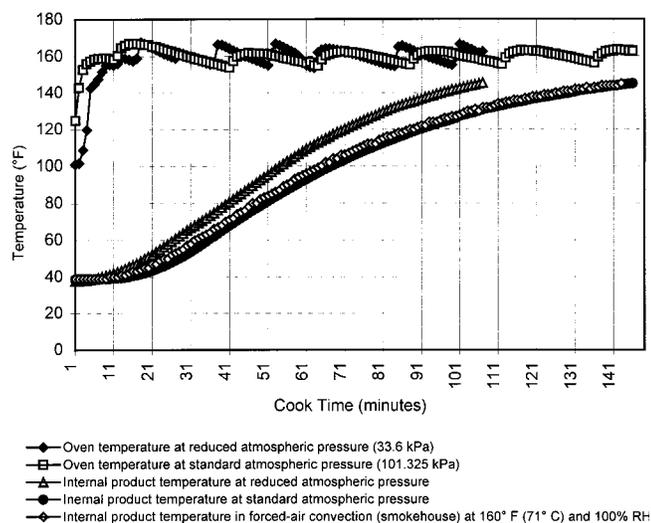
Cook loss vs. internal temperature of beef patties<sup>1</sup> manufactured with varying levels of textured soy protein concentrate.

<sup>1</sup>Beef patties formulated to contain 15.4% total protein, 25.0% total fat, and 58.0% total moisture with 0.0%, 9.4%, 18.9% or 28.8% hydrated textured soy protein concentrate. Patties were cooked on a flat griddle at a temperature of 325°F (162.8°C).

were weighed prior to and after cooking from a frozen (-14°C) state on a flat griddle set at 163°C, similar to the procedures outlined by AMSA (1994). Cook times ranged from 5 to 6.5 minutes (30 second intervals). Cooking losses were calculated for each treatment after each cook time by averaging the loss from 2 patties. Internal temperature was recorded for individual patties similar to the procedures outlined in the PG & E report (Kaufman, et al. 1989). After reaching the prescribed cook time, patties were removed, stacked, and placed in an insulated chamber. A group of 4 copper/constantan thermocouples was inserted into the approximate center of the patties. The probes were arranged at specific heights so that when inserted, the tip of each probe resided near the center of each patty. The highest temperature reached for each patty was recorded as the final internal temperature. Four replicates per treatment were cooked at the 5 and 6.5 minute cook time interval, and 6 replicates cooked at the 5.5 and 6 minute interval. Average values were plotted for internal temperature and cook loss. A simple linear trend line was plotted and corresponding coefficient of determination ( $R^2$ ) calculated (Figure 4). Except for Treatment 4 (8.0% TSPC), the  $R^2$  values indicate a relatively weak cause and effect relationship. Standard deviations for internal temperature ranged from 1.3 to 10.2, and 0.3 to 4.4 for cook loss. Collection of the data was complicated by several uncontrolled variables, including griddle temperature cycles, or the fact that stacking patties results in continuous heat transfer from the hot surfaces to the core. In addition, difficulty exists in verifying the approximate geometric center of the patties when vertically inserting thermocouples. Increasing the number of observations and controlling certain variables may reduce the large standard deviations observed in this limited study.

Other products requiring a heat process to ensure the safety of the finished product are included in Table 5 accompanied by the appropriate MPI reference.

FIGURE 5.



Time/Temperature Plot of Beef Semitendinosus Thermally Processed Under Standard or Reduced Atmospheric Pressure.

## Performance Standards

In May 1996, FSIS published a proposed rule outlining performance standards in lieu of the current regulations for the production of certain meat and poultry products. The proposal recommends converting the current regulations governing the production of cooked beef, roast beef, and cooked corned beef; fully cooked, partially cooked, and char-marked uncured meat patties; and certain fully and partially cooked poultry products, from a "command-and-control" format to performance standards. These performance standards indicate the objective level of performance which establishments must meet in order to produce safe and unadulterated products, but allow the use of plant-specific processing procedures other than those outlined in the current regulations (USDA, 1996). This flexibility would allow establishments the ability to employ innovative, unique, or customized processing procedures for the manufacture of these products.

The proposed performance standards are based upon quantifiable microbiological pathogen reduction requirements. For ready-to-eat products, establishments would be required to meet three performance standards: lethality, stabilization, and handling. The lethality standard requires a significant reduction in the number of pathogenic microorganisms in the product; the stabilization standard requires that establishments prevent vegetative spore-forming bacteria from growing within the product and producing toxin; the handling standard would require establishments to prevent recontamination of cooked product by infectious pathogenic microorganisms. For cooked beef, roast beef, and cooked corned beef, as well as cooked poultry products

described in 9 CFR 381.150, FSIS is proposing that the lethality performance standard be a 7-D reduction in *Salmonella*. For these same products, the stabilization performance standard requires not more than a 1-decimal log multiplication of *C. Perfringens*. The proposed lethality standard for fully cooked, uncured meat patties has been established at a 5-D reduction in *Salmonella*. The proposed rule indicates that when the current provisions in the regulations regarding time/temperature combinations for heating and cooling are applied, the proposed lethality and stabilization standards would be met. Therefore the current regulations would be retained in the CFR as examples of methods which establishments can use to meet the new performance standards. Establishments may continue to employ these methods in order to maintain compliance.

## Innovations In Thermal Processing

The current regulatory requirements regarding time and temperature for thermal processing have been based primarily on the destruction of microorganisms through conventional methods of forced convection, steam, or water cooking. However, the proposed rule opens the door for alternative and innovative methods of thermal processing. In a recent survey of manufacturing trends conducted by *Food Engineering* magazine, executives at food processing establishments were asked to rate the commercial potential of "new/unique process technologies", several of which included thermal processing systems (Morris, 1997). Interestingly, several of these same systems, including electrical resistance (ohmic) cooking, modified pressure cooking, and microwave sterilization, were cited as new process developments during the 22<sup>nd</sup> European Meeting of Meat Research Workers Congress (Bengtsson, 1976). A brief description of several "nontraditional" methods of thermal processing follows.

### Infrared

Infrared radiation in the wavelength range of approximately 0.8-400mm can be generated by a variety of means to obtain operating temperatures in the range of 500-2500°C. Electrically heated radiants include filaments sheathed in metal, silica, or quartz tubes, or by tungsten filament lamps (Brennan, et al. 1990). A recent innovation in infrared thermal processing of meat products involves directing a gas burner flame against a cylindrical or elliptical wall to generate radiant heat in the range of 650-815°C (Forney, et al. 1996). This radiant wall system also utilizes steam injected into the processing zone to create an oxygen-deficient atmosphere that eliminates flaming or smoking of rendered material. Infrared energy is characterized by strong surface absorption and low penetration, which results in rapid sealing and browning of outer layers (Brennan, et al. 1990). Full cooking of certain meat products is possible but depends upon product size, grind, and other considerations (Cornelius, 1997). Evaluation and application development is currently in progress at the University of Georgia for ther-

mal processing of meat and other foods, and specifically for surface microbial reduction in raw pork and poultry (Tolledo, 1997).

### Reduced Atmosphere

Thermal processing of food products at pressures above 1 atmosphere is well understood as it relates to retort cooking. Cooking at reduced atmospheric conditions is considerably less well documented. Bengtsson (1976) reported that Beer (1975) studied the effect of reduced pressure during deep fat frying. More recently a system has been introduced which utilizes reduced pressure to produce saturated steam. In principle, at equal temperatures, saturated vapor possesses greater specific volume and heat energy than moist air at standard atmospheric pressure (14.7 psia; 101.3 kPa). For example, saturated water vapor at 160°F (71°C) and an absolute pressure of 4.75 psia (32.57 kPa) has a specific volume of 77.19 ft<sup>3</sup>/lb (4.84 m<sup>3</sup>/kg) and latent heat of vaporization—expressed as enthalpy—of 1129.8 Btu/lb (2627.75 kJ/kg), while moist air (atmospheric pressure) at the same temperature has a specific volume and enthalpy of 23.08 ft<sup>3</sup>/lb (1.432 m<sup>3</sup>/kg) and 376.74 Btu/lb (852.71 kJ/kg), respectively (ASHRAE Handbook, 1981). This indicates that the energy transfer resulting from the phase change from steam condensing to liquid at the product surface is much greater for saturated steam at reduced pressure than for moist air at standard atmospheric pressure. Limited evaluation of reduced atmosphere thermal processing of injected beef *semitendinosus* has been conducted at our facility (Figure 5). Product core and oven temperatures were monitored each minute for similarly sized product thermally processed under static conditions at 160°F (71°C) and either standard atmospheric pressure (moist air) or partial vacuum at approximately 4.75 psi (32.57 kPa). Product processed under reduced atmospheric pressure took approximately 25% less time (107 min vs. 145 min) to reach the same internal temperature (145°F; 62.8°C). Product of similar size and weight was processed in a forced-air convection oven (smokehouse) at wet and dry bulb settings of 160°F (71°C) followed a similar heating pattern as that cooked under static conditions at standard atmospheric pressure.

### Radio Frequency

Substances containing water or other polar molecules absorb radio frequency (rf) energy efficiently; therefore rf cooking is applicable to foods (Lund, 1975). Radio frequency heating can be accomplished by either placing the object in a resonance cavity (microwave heating) or between parallel electrodes (dielectric heating). In dielectric or volume heating, an electric field is established between two electrodes and the polarity is rapidly reversed. Heating is established by molecular friction due to rapid orientation of dipolar molecules in the target material under the influence of the high frequency alternation of the applied field (Brennan, et al. 1990). The term “volume heating” is used to describe

this process because energy is absorbed within the product, in contrast to convection, conduction and infrared heating, where heat energy is absorbed at the surface of the product (Lund, 1975). A method and oven for the heat curing of raw meat products is described in European Patent 0287610 B1 (Jensen and Pedersen, 1992), whereby the product is conveyed through an electromagnetic field. The patent claims that the continuous heating of a meat medium of up to 15 cm in thickness, by means of one or more pairs of electrodes generating electromagnetic frequencies, can be achieved within a few minutes. One manufacturer of this type of equipment (APV Engineering AS, Silkeborg, Denmark) claims their volumetric heating process achieves core temperatures in a cooked ham product of 72°C within 120 seconds.

### Summary

Regulatory agencies are demanding more accountability from food processors to demonstrate that their products are safe. USDA has issued regulations requiring meat and poultry establishments to implement HACCP systems as a means of controlling their processes to prevent microbial contamination. Foodservice establishments would benefit by establishing process controls based on identification and understanding of their own critical control points. Good manufacturing practices must include time and temperature controls. Moreover, control of these parameters is critical to the implementation of a successful HACCP plan. Optimizing the relationship between time and temperature in the manufacture of processed meat products requires knowledge of the basic principles of heat and mass transfer. This knowledge begins with comprehension and recognition of the capability and variation of all systems involved within the manufacturing process. Consideration must also be given to the relationship of these systems to variations in raw material and product composition. Ultimately, the application of these principles must be employed relative to their relationship to consumer acceptability standards.

### References

- Ahmed, N.M.; Conner, D.E.; Huffman, D.L. 1995. Heat-resistance of *Escherichia coli* O157:H7 in meat and poultry as affected by product composition. *J. Food Sci.*, 60:3, 606-610.
- AMSA. 1995. Research Guidelines for Cookery, Sensory Evaluation and Instrumental Tenderness Measurement of Fresh Meat. National Livestock and Meat Board, Chicago, IL.
- ASHRAE. 1981. ASHRAE Handbook, Fundamentals. American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., Atlanta, GA., 6.1-6.16.
- ASTM. 1995. Standard test method for performance of griddles. Annual Book of ASTM Standards - End Use Products. (ASTM: Philadelphia) Vol.15.07. pp 760-773
- Ball, C.O.; Olson, F.C.W. 1957. 'Sterilization in Food Technology' 1<sup>st</sup> Edn. (McGraw-Hill Book Company, Inc.: New York).
- Barbut, S; Findlay, C.J. 1991. Influence of sodium, potassium and magnesium chloride on thermal properties of beef muscle. *J. Food Sci.*, 56:1, 180-182.
- Bengtsson, N. 1976. Recent developments in heat treatment and heat sterilization. 22<sup>nd</sup> European Meeting of Meat Research Workers Congress Documentation. Volume II, J0:1-J0:7.

- Brennan, J.G.; Utters, J.R.; Cowell, N.D. 1990. 'Food Engineering Operations' 3<sup>rd</sup> Edn. (Elsevier Science Publishing Co., Inc.: New York). pp. 265-282.
- Brewer, M.S.; Novakofski, J. 1997. Cooking rate, pH and final endpoint temperature effects on instrumental and visual color, and cook loss of lean ground beef. Unpublished.
- Buzby, J.C.; Roberts, T. 1996. ERS updates U.S. foodborne disease costs for seven pathogens. 'Food Review', USDA Economic Research Service. Sept. - Dec. pp. 20-25.
- CFR. 1994. Code of Federal Regulations Title 9, Chapter III. National Archives and Records Administration, Washington, DC.
- Cornelius, D. 1997. Personal communication.
- Cross, H.R.; Berry, B.W. 1980. Factors affecting palatability and cooking properties of ground beef patties - frozen lean, patty size, and surface treatment. *J. Food Sci.*, 45: 1463-1465.
- Forney, R.B.; Brown, E.C. 1996. Radiant wall oven and method of using the same. U.S. Patent 5,521,312.
- Goodfellow, S.J.; Brown, W.L. 1978. Fate of *Salmonella* inoculated into beef for cooking. *J. Food Protection*, 41: 8, 598-605.
- Hague, M.A.; Warren, K.E.; Hunt, M.C.; Kropf, D.H.; Kastner, C.L.; Stroda, S.L.; Johnson, D.E. 1994. Endpoint temperature, internal cooked color, and expressible juice color relationships in ground beef patties. *J. Food Sci.*, 59: 3, 465-470.
- Hanson, R.E. 1990. Cooking technology: heat and moisture transfer in meat products. 43<sup>rd</sup> Reciprocal Meat Conference Proceedings.
- Holtz, E.; Skjöldebrand, C.; Bognar, A.; Piekarski, J. 1984. Modeling the baking process of meat products using convection ovens. In: 'Thermal Processing and Quality of Foods', (Elsevier Science Publishing Co., Inc.: New York). pp. 329-338.
- Jensen, H.C.S.; Pedersen, H. 1992. Method and oven for the heat curing of raw meat products. European Patent 0 287 610 B1.
- Kaufman, D.A.; Fisher, D.; Nickel, J.; Saltmarch, M. 1989. Development and application of a uniform testing procedure for griddles. Pacific Gas and Electric Company, San Ramon, CA.
- Lund, D. 1975. Heat transfer in foods. In: 'Principles of Food Science Part II, Physical Principles of Food Preservations', O.R. Fennema, Ed. (Marcel Dekker, Inc.: New York). pp. 11-30.
- Martens, H.; Vold, E. 1976. DSC studies of muscle protein denaturation. 22<sup>nd</sup> European Meeting of Meat Research Workers Congress Documentation. Volume II, J9:3-J9:6.
- Mendenhall, V.T. 1989. Effect of pH and total pigment concentration on the internal color of cooked ground beef patties. *J. Food Sci.*, 54: 1, 1-2.
- Monagle, C.W.; Toledo, R.T.; Saffle, R.L. 1974. Effect of smokehouse temperature, humidity, and air velocity on rate of heating and quality of frankfurters. *J. Food Sci.*, 39: 602-604.
- Morris, C.E. 1997. Survey of manufacturing trends. *Food Engineering*. 69:3, 67-70.
- Perez, M.G.R.; Calvelo, A. 1984. Modeling the thermal conductivity of cooked meat. *J. Food Sci.*, 49:152-156.
- Skjöldebrand, C.; Hallström, B. 1980. Convection oven frying: heat and mass transport in the product. *J. Food Sci.*, 45: 1347-1353.
- Schmidt, G.R.; Trout, G.R. 1984. pH and color. *Meat Industry* 30(8): 30.
- Toledo, R. T. 1997. Personal communication.
- Trout, G. 1989. Variation in myoglobin denaturation and color of cooked beef, pork, and turkey meat as influenced by pH, sodium chloride, sodium tripolyphosphate, and cooking temperature. *J. Food Sci.* 54: 3, 536-540.
- Trout, E.S.; Hunt, M.C.; Johnson, D.E.; Claus, J.R.; Kastner, C.L.; Kropf, D.H. 1992a. Characteristics of low-fat ground beef containing texture-modifying agents. *J. Food Sci.* 57: 1, 19-24.
- Trout, E.S.; Hunt, M.C.; Johnson, D.E.; Claus, J.R.; Kastner, C.L.; Kropf, D.H.; Stroda, S. 1992b. Chemical, physical and sensory characterization of ground beef containing 5 to 30 percent fat. *J. Food Sci.* 57: 1, 25-29.
- USDA. 1982. Production requirements for cooked beef, roast beef, and cooked corned beef. Interim final rule. Fed. Reg. 47: 31854.
- USDA. 1983. Production requirements for cooked beef, roast beef, and cooked corned beef. Final rule. Fed. Reg. 48: 24314.
- USDA. 1993a. Handling and storage requirements for uncured meat patties. Final rule. Fed. Reg. 58: 41151.
- USDA. 1993b. Instructions for verifying internal temperature and holding time of meat patties. FSIS Directive 7370.1.
- USDA. 1995. Compilation of issuances on cooked meat and poultry product temperatures. FSIS Directive 7370.2.
- USDA. 1996. Performance standards for the production of certain meat and poultry products. Proposed rule. Fed. Reg. 61: 19564.
- USDA. 1997. USDA advises consumers to use a thermometer when cooking hamburger. FSIS News and Information. Washington, DC.