EFFECT OF ELECTROCHEMICAL CURING TECHNOLOGY ON THE DIFFUSION OF CERTAIN CURING AGENTS AND PHYSICOCHEMICAL QUALITY CHARACTERISTICS OF CURED MEAT

By

A. M. SHAMSUL ALAM

Bachelor of Science
Bangladesh Agricultural University
Mymensingh, Bangladesh
1973

Master of Science
University of Mysore
Mysore, India
1978

Master of Science
State University of New York
Albany, New York
1982

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
DOCTOR OF PHILOSOPHY
May, 1988

EFFECT OF ELECTROCHEMICAL CURING TECHNOLOGY

ON THE DIFFUSION OF CERTAIN CURING AGENTS

AND PHYSICOCHEMICAL QUALITY

CHARACTERISTICS OF

CURED MEAT

Thesis Approved:

John J. Guenther
Thesis Advisor

P. L. Claypool

Igor L. Ebro

George V. Odell

Stanley E. Gilliland

Norman N. Durham
Dean of the Graduate College

ACKNOWLEDGMENTS

I would like to express sincere appreciation to Dr. J. J. Guenther, Professor of Animal Science (Food Science Program) for his guidance, assistance and encouragement during this study and preparation of thesis.

I acknowledge the assistance of Dr. P. L. Claypool, Professor of Statistics in designing the experiment, analyses and interpretation of data. I appreciate the cooperation of Dr. D. M. Kinsman and Dr. J. W. Riesen, Professors of Animal Science, The University of Connecticut in executing some computer programs and correcting the manuscript.

I am indebted to Dr. S. E. Gilliland, Professor of Animal Science (Food Science Program), Dr. G. V. Odell, Professor of Biochemistry, and Dr. L. L. Ebro, Professor of Food Nutrition and Institution Administration, members of my advisory committee for their advice, encouragement and constructive criticism.

My special thanks are extended to Mrs. Kris Novotny for her patience, cooperation and technical assistance in data collection.

I am also thankful to Dr. R. Henrickson, Dr. L. Walters, Dr. G. Dolezal, Dr. F. Ray, Dr. H. Turgut, Dr. B. Rao, and fellow graduate students Dr. D. Hale, Dr. N. Rashid, Dr. O. Lara, Dr. G. Arganosa, B. Kinney, A. Bufford and C. Nelson for their professional companionship.

I am grateful to all my family members for their thoughtfulness, encouragement and understanding during the entire course of study.

I also acknowledge the financial support from the Department of Animal Science and Industry, Oklahoma State University.

DEDICATION

THIS DISSERTATION IS DEDICATED

TO

MY BELOVED WIFE

REJINA

WHOSE LOVE, SACRIFICE AND ENCOURAGEMENT

MADE THIS DEGREE POSSIBLE

AND

TO

MY WONDERFUL DAUGHTER

TASNEEM

WHOSE ARRIVAL MADE A WORLD OF DIFFERENCE

IN MY LIFE

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Table | Page

Table | Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION AND REVIEW OF LITERATURE

Difficulty in developing a uniform color and the extensive time required to effect the curing reaction are two well recognized problems with cured meat products. Although "curing" has been used to preserve meat from ancient times, advanced scientific principles were not used until the middle of this century. Despite an atmosphere of advanced engineering concepts in equipment design and greater mechanization in meat curing technology the two problems mentioned above remain with cured meat products.

Originally, curing was used mostly to preserve meat during times of plenty to carry over to times of scarcity without refrigeration. In the early days it was necessary to use very high concentrations of salt which was rubbed on the surface of the meat--dry cure (Bard and Townsend, 1971). The objective of modern meat curing technology, however, is to manufacture many varieties of superior quality meat items, generally mild or wet cured. The use of lower salt concentrations makes it more difficult to stabilize the cured meat color in a short time.

In the living tissue, myoglobin serves as a reserve supply of oxygen and also facilitates the movement of oxygen within the muscle. After the animal is slaughtered, this compound becomes the primary postmortem muscle pigment and is mainly responsible for the meat color

we associate with quality. Since the amount of this pigment varies with age, sex, species, altitude (Medeiros et al. 1988) and muscle activity, the intensity of meat color is also variable.

As revealed by X-ray crystallography myoglobin is extremely compact with 75% of the single polypeptide chain folded in an alpha-helical conformation (molecular weight 17,800) having 153 amino acid residues (Stryer, 1975). Nonpolar residues are present exclusively in the inside of myoglobin and outside contains both polar and nonpolar residues. The oxygen binding ability of myoglobin is due to the presence of a heme prosthetic group. An organic part and an iron atom make up the heme. The organic part is known as protoporphyrin and it is made up of four pyrrole groups held together by methene bridges to form a tetrapyrrole ring. There are four methyl, two vinyl and two propionate side chains attached to the tetrapyrrole ring system.

Out of 15 possible isomers only one is found in biological systems. This is known as protoporphyrin IX. The four nitrogens in the center of the ring are bound to the heme iron atom. On either side of the heme plane the iron atom can form two additional axial bonds. These two bonds are known as fifth and sixth coordinate positions. An imidazole group of the proximal histidine residue of the myoglobin polypeptide chain occupies the fifth coordinate position. The sixth coordination position is the oxygen binding site and is on the other side of the heme plane. This sixth coordinate position is the most important site for meat color reactions. In order to complete the myoglobin structure this position can take part in a reaction to form either a covalent bond or an ionic bond with any reacting species which has an extra pair of electrons.

The bright color of fresh or cured meat is a result of covalent bond formation at the sixth coordination position (Dryden and Birdsall, 1980). Depending upon the presence or absence of reducing substances and ferric ion covalent complexes, the heme iron can exist in two states: Ferrous (Fe^{2+}) and Ferric (Fe^{3+}). An adequate supply of molecular oxygen on the cut surface of fresh meat forms oxymyoglobin giving the bright red color due to myoglobin's great affinity for the dioxygen biradical (Giddings, 1977). In the interior tissue, myoglobin is in the reduced state and has a dark purple red color.

In a meat curing process when nitrite is added, a brown colored compound (metmyoglobin) forms because the heme pigment gets oxidized to the ferric state (Fe^{3+}) by nitrite. This metmyoglobin can be reduced by nitric oxide formed due to various endogenous or exogenous reducing agents. The nitric oxide forms a covalent bond at the sixth position ligand of cured meat which binds the iron via a nitrogen atom to form an extremely stable redish-pink color complex: nitrosomyoglobin. Ultimately, nitrosohemochrome (pink) is produced by heat. At the same time, myoglobin can reduce nitrate to generate nitric oxide for further reaction. The function of other reducing agents is to make sure that the myoglobin remains in its reduced state (Fe^{2+}) so that it can generate more nitric oxide by reducing nitrite, continuing the cured color reaction.

The cured meat color development can be adequately accomplished with 25-50 ppm nitrite (Herring, 1973). Usually 100-150 ppm of nitrite is added to meat for curing which is in excess of what is needed for color development only. Therefore, the residual nitrite that remains after the

initial cured color reaction acts as a source of continued supply of nitric oxide for the stabilization of cured color during storage and distribution. A brown color results when oxygen is uncoupled from the myoglobin pigment of uncured meat. On the other hand, the cured meat will maintain a pinkish-red color for a longer period of time due to the chemical changes in the myoglobin pigment (denaturation of globin), muscle proteins and various other muscle tissue components during processing and post-proccessing handling.

Contrary to the popular belief, sodium nitrite does not impart color to cured meat; it merely fixes or stabilizes the color of cured meat (Dryden and Birdsall, 1980). Cured cooked meat color is fixed after myoglobin reacts with nitric oxide, produced from nitrite under reduced atmosphere, and forms the stable denatured nitrosomyoglobin pigment after heating (Cassens et al., 1979; Fox, 1966; Giddings, 1977; Lee and Cassens, 1976; Rust and Olson, 1973; Tarladgis, 1962; Fujmaki et al, 1975; Dymicky et al, 1975; Woolford et al, 1976; Woolford and Cassens, 1977; Goutefonegea et al, 1977; Oelingrath, 1988; Buchowsky et al, 1988; Lee and Shimaoka, 1985).

As mentioned previously, heterogeneous color formation and longer time required to accomplish curing are major problems associated with cured meat processing. To overcome these problems, various physical forces have been used. One widely used method is the multineedle pump, where the needles having numerous apertures are penetrated into the muscles and curing solutions are pumped through them. This helps to distribute the curing ingredients throughout the musculature and accelerates the diffusion process by shortening the distance to be travelled by curing agents. Highly automated and sophisticated pumps and needles

are being used today to inject predetermined amounts of curing solutions. But, even with this automation and sophistication, complete and homogeneous cured color stabilization is not achieved.

Other physical forces such as friction (massaging), impact (tumbling), pressure, alternate pressure, vacuum and ultrasonic sound waves have been used to improve the meat curing technology with some success (Addis and Schanus, 1979; Krause et al., 1978; Ockerman et al., 1978; Ockerman and Organisciak, 1978; Ockerman and Dowiercial, 1978; Weiss, 1974; Siegel et al., 1978; Ford et al., 1978; Dreano and Noyelle, 1980; Reynolds et al., 1978).

Electrical current is a form of energy and it was thought that the flow of electrical current might accelerate the rate of dissociation of the larger compounds ($NaNO_2$ and NaCl) into their respective smaller ions (NO_2^-, Cl^- and Na^+). Thus, a rapid dissociation of curing ingredients might ensure increased supply of the smaller ions around the muscle tissue and build up a concentration gradient in a short time. Such a concentration gradient might accelerate the diffusion process and decrease the time required to form a homogeneous cured meat color. Theoretically, only 15% of the total added nitrite would be required to fix the color of cured meat (Birdsall, 1979). Use of electrical current might lower the amount of nitrite needed to fix the cured meat color. Therefore, the use of an electrochemical curing process to help diffuse curing ingredients into meat tissue might open a new era in cured meat processing technology.

CHAPTER II

MATERIALS AND METHODS

Animal and Muscle Selection

Experimental muscles were obtained from the left and right loins of 18 market weight hogs. One animal was slaughtered each week at the Oklahoma State University meat laboratory. The Longissimus Dorsi (LD) muscle was excised from each loin between the eighth thoracic vertebra and the sacro-illiac joint at 24 hours postmortem. Most of the knife trimable fat was removed and a 38.10 cm long section was selected for curing.

Electrochemical Curing Procedures

Curing experiments were conducted at approximately 5°C in two rectangular plexiglass tanks (61 cm long, 31 cm wide and 46 cm high) as shown in Figures 1 and 2. One carbon electrode was placed on each end of the treatment tank (2.54 cm away from the muscle ends and 1.27 cm away from the tank wall). The posterior end of LD always faced the positive electrode and the anterior end faced the negative electrode. Nine liters of a curing solution were used containing sodium nitrite (500 ppm, Fisher Scientific Company, Fairlawn, New Jersey), sodium chloride (10,000 ppm, Morton Thiol Inc. Food Grade Salt), sodium tripolyphosphate (5,555 ppm, Grifith Laboratory, USA), sodium isoascor-

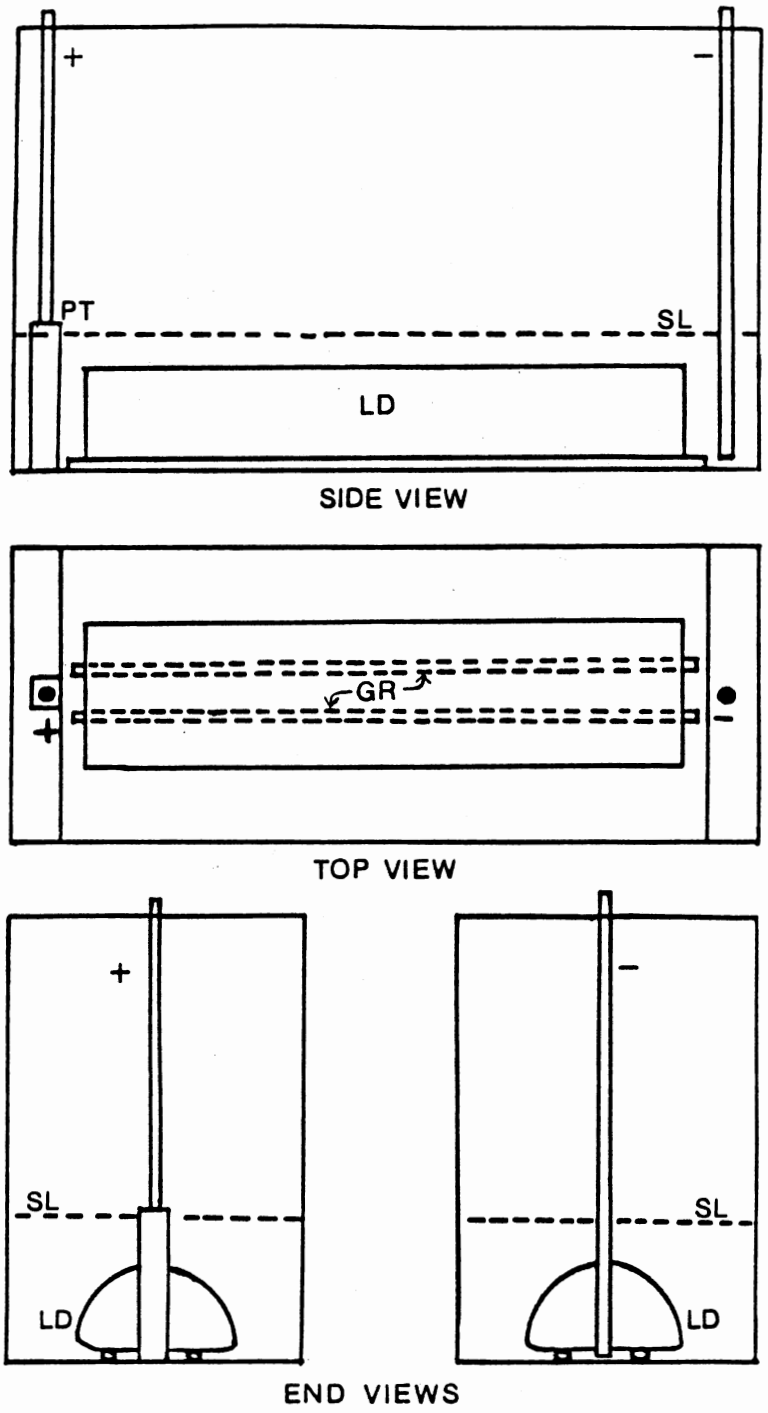

Figure 1. Electrochemical curing arrangements showing positive electrode (+), negative electrode (-), glass rods (GR), Longissimus dorsi muscle (LD), paper trap (PT), solution level (SL).

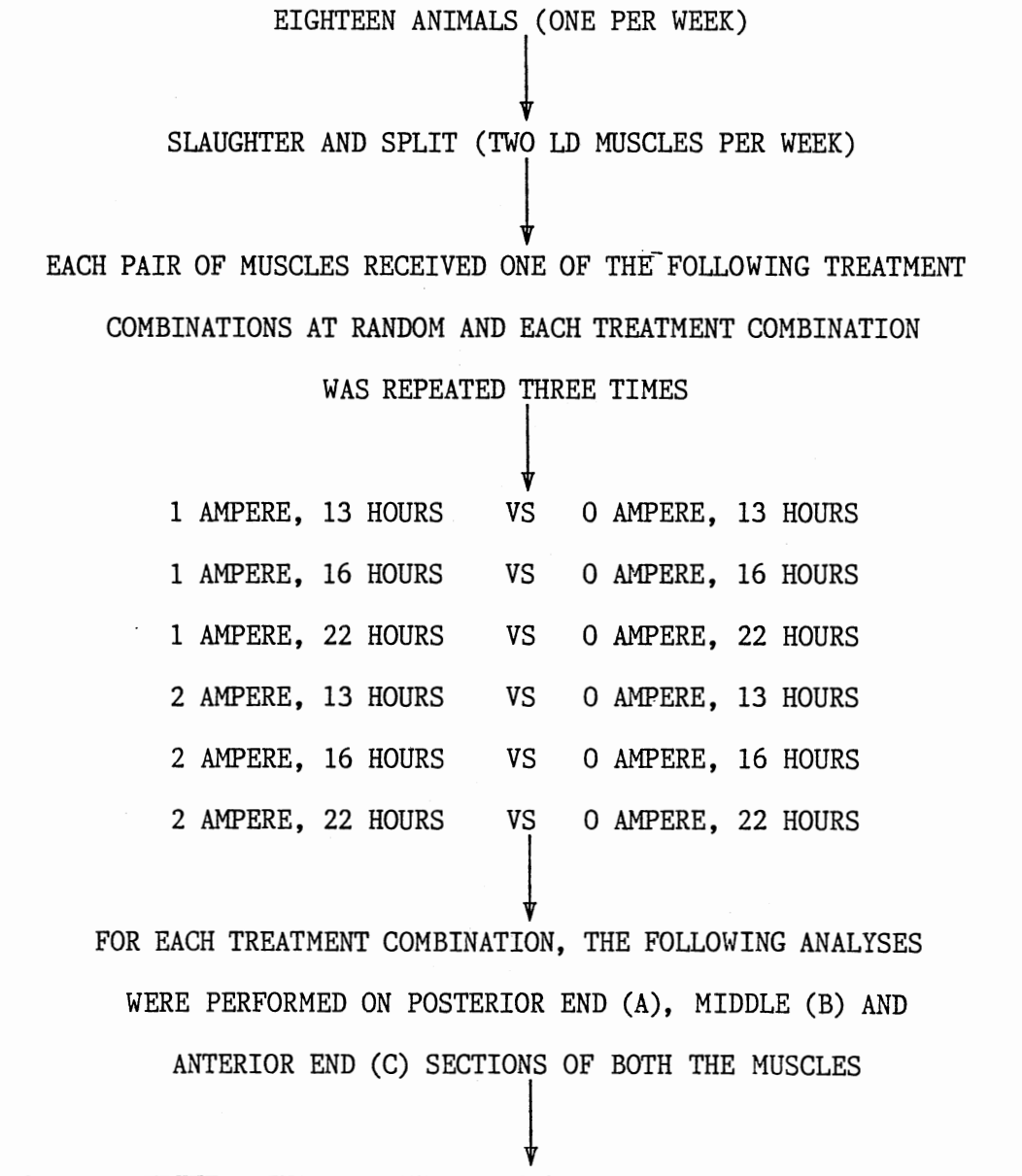

Figure 2. Schematic representation of electrochemical curing experiment

bic acid (555 ppm, B. Heller and Company, BW-0058), and sucrose (66,666 ppm).

A cubical trap with one side open was made from heavy filter paper and placed under the positive electrode to catch and prevent the movement of disintegrated carbon particles into the curing solution. A Hewlett-Packard D.C. power supply (Model 8000A) unit was connected to this tank with carbon electrodes, curing solution was added, the tank was then placed in a plastic container (80 cm long, 50 cm wide and 60 cm high), ice flakes (approximately 8 cm thick layer) were used in between the tank and plastic container to keep the curing solutions cool (5°C ±3). One LD muscle was placed in the geometrical center of the tank with two glass rods (38.1 cm long and 0.64 cm in diameter) underneath so that the muscle suspends in the solution and gets maximum surface area exposed. The power supply was turned on to start the flow of electrical current. A Simpson multimeter (Model 464) was used to monitor volts and amperes. The control "treatment" was also conducted as outlined previously except that no electrical current was used.

Cooking Procedures

After diffusion of curing agents the muscles were removed from tanks, dried of excess curing solution by using paper towels, weighed and heated (68°C internal) in a convection oven (Blodgett Co., Inc., USA) according to the following oven temperature schedule: first 30 minutes — 54°C, second 30 minutes — 66°C, and the final oven temperature was 93°C until the meat internal temperature of 68°C was achieved. The muscles were then placed in a refrigerator, cooled to 4°C meat internal

temperature, wrapped in a plastic bag to avoid moisture loss and used for analyses within 36 hours.

Analytical Procedures

Sample Procurement

After chilling, each muscle was divided into three sections of the same thickness (approximately 10 cm)--A (posterior end), B (middle) and C (anterior end). Each section was divided into two equal subsections; subsection 1 (near the anterior end) and subsection 2 (near the posterior end).

Juiciness (Pressed Fluid Ratio)

Two 1 gram samples were cut from the approximate geometrical center of a thin (2 mm) center slice of the first subsection to determine pressed fluid ratio. Each sample slice was then placed flat on the center of a Whatman No. 1 (12.5 cm diameter) qualitative filter paper and pressed in between two plexiglass plates for one minute at 4536 Kilogram per square centimeter using the ram of a Carver hydraulic press (Thompson, 1981). Prior to use, the filter papers were held in a desiccator containing saturated potassium chloride to ensure constant humidity and care was taken to avoid moisture evaporation from the meat sample. After the meat sample was pressed, the resulting meat ring was traced on wax paper with a soft pencil, pressed meat sample was removed, the filter paper dried for 4 hours at 100°C in a drying oven and each area (meat ring--inner ring and the juice ring--outer ring) was measured twice with a compensating Polar Planimeter. A dimensionless ratio was obtained which represented the pressed fluid in

that sample (Syre et al.,1963), as shown below:

$$\text{Pressed Fluid Ratio} = \frac{\text{Juice ring area}}{\text{Meat ring area}} \times 100$$

Thus, the larger the ratio, the more pressed fluid (or juiciness) per unit area of sample.

Cooked Meat pH

Five grams of meat sample were collected from the center slice of the first subsection (next to the area from which the juiciness samples were collected) and placed in a 100 ml beaker containing 50 ml distilled water and homogenized for 30 seconds in a Brinkman Polytron homogenizer. A digital Corning 130 pH meter was calibrated with buffer (5.00 ± 0.02) and pH was measured with an Orion combination electrode. Each pH reading was recorded one minute after immersion of the electrode into the meat slurry. A magnetic stirrer was used to ensure continuous movement of the slurry.

Cured Color Area

Total cross sectional area and any uncured area of the freshly opened center slice of the first subsection were traced on wax papers by using a soft pencil and measured by a compensating Polar Planimeter. Uncured area was subtracted from the total area and the following equation was used to compute the percentage of cured color area:

$$\text{Percent Cured Color Area} = \frac{\text{Total Cross Sectional Area} - \text{Uncured Area}}{\text{Total cross sectional area}} \times 100$$

Cured Color Intensity (L-value)

The second subsection was chilled for 24 hours at 4°C (± 2°C), divided into 2 sub-subsections (2.5 cm thick) and the freshly opened surfaces were utilized for color evaluation. A Hunter colorimeter (photovolt reflection meter, model 610) with a 610-Y search unit was used to measure the percent reflectance from the cut surface of the sample. A green filter in the search unit was adjusted to 100% reflectance using a magnesium oxide surface; then a Munsell 5R 5/12 chip was utilized as a standard. The degree of lightness was measured (10 = white, 0 = black) by converting it to Hunter L-values. Thus, the larger the lightness value the brighter is the color.

Tenderness (Warner-Bratzler Shear Value)

The first subsection (closer to the anterior end) was selected after the cured color area determination and used for tenderness estimation. A stainless steel meat corer was used to collect 3 cores (1.91 cm in diameter) parallel to the direction of the plurality of muscle fibers from the approximate geometrical center by avoiding any uncured area. The shear force values were determined using a Warner-Bratzler shear apparatus and shearing at right angles to the direction of the muscle fibers.

Curing Solution pH

At two hours interval, 10 ml curing solution was collected and pH was measured immediately with a digital Corning-130 pH meter after calibrating with a buffer (9.00 ± 0.04). The curing solution was added

back to the curing tank after pH determination.

Temperature of Curing Solution

The temperature of curing solution was monitored by suspending a glass thermometer near the geometrical center of the solution.

Chemical Analysis

After L-value determination, the second subsection was finely cut, thoroughly mixed and duplicate samples were taken for the following analyses:

Residual Sodium Nitrite

Residual sodium nitrite was analyzed by colorimetric method (AOAC, 1984).

Denatured Nitrosomyoglobin Pigment

The denatured nitrosomyoglobin pigment value was colorimetrically analyzed according to Hornsey (1956).

Total Pigment

The colorimetric analysis of total pigment value was carried out according to Hornsey (1956).

Chloride Ion

Ten grams of finely cut meat samples were placed in a 100 ml beaker and heated (80^{o}C) with 50 ml water and 5 ml acetic acid for 5 minutes. A chloride ion-selective electrode (Orion, 1980) was stand-

ardized with solutions of known strengths (100 ppm and 1000 ppm) and chloride ion concentration in meat extract was measured.

Sodium Ion

One gram of sample was taken into a 125 ml beaker, 100 ml distilled water was added, swirled vigorously to break any lump and 10 ml of food-sodium buffer was added. The sodium electrode (Orion, 1980) was calibrated with known strengths (100 and 1000 ppm) and the sodium ion reading of sample extract was recorded.

Moisture Content

Moisture content was determined by weight loss method by drying for 24 hours at 110°C (AOAC, 1984).

Experimental Design and Data Analysis

The experiment was conducted as a split-split plot (Steel and Torie, 1980) with a 2 X 3 factorial arrangement of treatments--FAT (factor A was electrical current at two levels and factor B was time at three levels) applied in a completely randomized design (CRD) to the whole plots (animals). Within each animal the LD muscles from the loins were randomly assigned to the control and treated solutions (subplot treatment factor), then each muscle was sliced into three sections representing positions (sub-subplot treatment factor) from the anterior to the posterior end of the muscle.

The data analysis was performed in three steps. First, "Experiment 1" or the 2-Ampere data were analysed as a split-split plot

as described above except there was no electrical current factor among the whole plots. Secondly, "Experiment 2" or the 1-Ampere data were analyzed in the same manner as "Experiment 1". Finally, inferences about the effects of electrical current (1 Ampere vs 2 Amperes) were based on an analysis in which all data from the control samples were omitted and the remaining data were analyzed as a split plot with a 2 X 3 FAT in a CRD for the whole plots and positions were the subplot treatment factors.

The data were subjected to analysis of variance using Statistical Analysis System (SAS Institute, 1985). The F-test was used to determine if significant variations occurred among treatments. Means were compared using Duncun's Multiple Range test at the 5% level of significance. The SAS program was executed in the mainframe computers of Oklahoma State University Computer Center and The University of Connecticut Computer Center.

CHAPTER III

RESULTS AND DISCUSSION

Residual Sodium Nitrite

Sodium nitrite is the most important curing agent to fix the cured meat color and provide antimicrobial activity. Concentration of residual sodium nitrite in cured meat is an index of overall sodium nitrite diffusion. Residual sodium nitrite values are presented in Tables 1 and 2.

At the lower level of treatment (0 vs 1 Ampere, Table 1) sodium nitrite diffusion was increased at 13, 16 and 22 hours by 37.5% ($P = .016$), 54.3% ($P = .198$) and 63.2% ($P = .002$) respectively. There were no significant interactions of electrical current and position ($P > 0.05$, Table 25, Appendix) at any time period. Table 25 (Appendix) also indicates that the position effect was not significant ($P > 0.05$). As the curing time was increased the sodium nitrite diffusion also increased significantly for both control and electrochemically treated samples ($P = 0.0005$ and $P < 0.05$ respectively, Table 26, Appendix).

The data for the higher level of electrical current (0 vs 2 Amperes, Table 2) demonstrates significant interactions between electrical current and position at all three levels of curing periods ($P < 0.001$, Table 25, Appendix). Effects of position in the muscle was

TABLE 1

RESIDUAL SODIUM NITRITE VALUE (PPM)[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 1 AMPERE)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average
		ppm	ppm	ppm	ppm
0	A	44.83	42.27	58.67	48.59
	B	35.33	36.25	50.25	40.61
	C	29.35	36.58	56.83	40.92
	Average	36.51	38.37	55.23	43.37
1	A	52.75	46.42	58.67	52.55
	B	41.27	42.25	82.67	55.40
	C	56.58	89.00	129.00	91.53
	Average	50.20	59.22	90.11	66.49

[a]Each value is the average of 6 observations.

TABLE 2

RESIDUAL SODIUM NITRITE VALUE (PPM)[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 2 AMPERES)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average
		ppm	ppm	ppm	ppm
	A	47.27	56.00	55.92	53.06
0	B	41.33	56.42	43.76	47.03
	C	36.70	54.17	46.74	45.81
	Average	41.77	55.53	48.81	48.70
	A	50.63	63.00	37.83	50.48
2	B	42.52	58.00	35.05	45.19
	C	165.58	158.83	147.75	157.39
	Average	86.24	93.28	73.54	84.35

[a]Each value is the average of 6 observations.

also significant ($P < 0.0001$, $P = 0.001$ and $P < 0.0001$ for 13, 16 and 22 hours respectively, Table 25, Appendix). The pattern of interaction was more or less similar with a much greater increase in diffusion occurring in position C at each time. At position A the effect of electrical current was 7.1%, 12.5% and -32.3% at 13, 16 and 22 hours respectively and at position B the effect of electrical current was 2.9%, 2.8% and -20.0% respectively. However, at position C electrical current increased sodium nitrite diffusion at all three times (92.8%, 143.3% and 127.0% for 13, 16 and 22 hours respectively).

Analysis of data (Table 23, Appendix) for the lower level (1 Ampere) versus the higher level (2 Amperes) of electrical current treatment showed significant time by electrical current ($P = 0.005$) and position by electrical current ($P = 0.004$) interactions on sodium nitrite diffusion. The effect of 1 versus 2 Amperes electrical current was minimal at position A, somewhat higher at position B for 1 Ampere, while decidedly greater diffusion occurred for 2 Amperes at position C.

The significant interactions between time and electrical current ($P < 0.005$, Table 24, Appendix) resulted from a pronounced decrease in level of sodium nitrite diffusion value in the higher (2 Amperes) electrical current treatment between the 16 and 22 hour groups, while at the lower level (1 Ampere) of electrical current, diffusion increased in each of the successive time periods. However, it should be noted that the control samples of both levels of electrical currents also exhibited a similar pattern suggesting that differences in the animals or differences in uncontrolled variables between the two experiments may have contributed to this interaction.

Thus application of electrochemical curing increased sodium

nitrite diffusion with the higher level of electrical current (2 Amperes) at the anterior end of LD muscle and with increased time of curing in most cases. A higher degree of diffusion of sodium nitrite for position C (anterior end of LD muscle) in the treated samples was thought to be due to a more open microstructure of meat tissue in that section of the muscle, allowing more ions to diffuse. This could be also due to an electrochemical environmental effect on the orientation of the phospholipid bilayers of tissue membranes resulting in increased permeability.

Chloride Ion

Chloride ion concentration is an index of overall sodium chloride diffusion in the muscle tissue. Chloride ion data are presented in Tables 3 and 4.

At the lower level of electrical current treatment (0 vs 1 Ampere, Table 3), analysis of data indicated no significant ($P > 0.05$ Table 27, Appendix) interactions between position and electrical current on the effect of position in muscle on chloride ion diffusion. However, there were significant increases ($P < 0.05$, Table 27, Appendix) in chloride ion diffusion at 22 hours only due to electrochemical environment.

Application of the higher level of electrical current (0 vs 2 Amperes, Table 4) resulted in significant (Table 27, Appendix) interactions between position and electrical current ($P < 0.0001$, $P = 0.004$ and $P < 0.0001$ for 13, 16, and 22 hours respectively). The effect of position in muscle was also significant at all three time periods of curing. A similar pattern was observed for all three

TABLE 3

CHLORIDE ION CONCENTRATION (PPM)[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 1 AMPERE)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average
		ppm	ppm	ppm	ppm
0	A	1122	1201	1634	1319
	B	1118	1227	1460	1268
	C	1096	1223	1666	1328
	Average	1112	1217	1587	1305
1	A	1085	1211	1401	1233
	B	1140	1300	1832	1424
	C	1371	2451	2815	2212
	Average	1199	1654	2016	1623

[a]Each value is the average of 6 observations.

TABLE 4

CHLORIDE ION CONCENTRATION (PPM)[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 2 AMPERES)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average
		ppm	ppm	ppm	ppm
	A	1496	1464	1387	1449
0	B	1367	1551	1310	1409
	C	1181	1496	1389	1356
	Average	1348	1504	1362	1405
	A	1474	1525	1533	1510
2	B	1426	1548	1221	1396
	C	3850	3318	4370	3846
	Average	2250	2128	2375	2251

[a]Each value is the average of 6 observations.

positions with a much greater increase in diffusion at position C for all time periods.

The analysis of variance (Table 23, Appendix) of the lower (1 Ampere) versus the higher (2 Amperes) level of electrical current treatment showed significant ($P = 0.01$, Table 23, Appendix) interactions between position and electrical current and the effect of position in the muscle. While there were minimal effects of electrical current at position B (19.66%), position A showed somewhat increased diffusion (22.56%) and position C decidedly greater diffusion (137.11%). Thus, the interactions between position and electrical current were due to the high values of diffusion at position C for the 2 Ampere electrical treatment.

There were no interactions between time and electrical current ($P > 0.05$, Table 23, Appendix), but the 2 Amperes electrical current treatment showed somewhat decreased overall average chloride ion diffusion for 16 hour samples of 2127.82 ppm compared to 2249.81 ppm at 13 hours. This observation suggested that most of the chloride ion diffusion took place within 13 hours of curing and the meat tissue became saturated with chloride ions leaving little or no space for further diffusion.

Analysis of curing time data (Table 28, Appendix) indicated that as the curing time was increased, there was a significantly linear increase of chloride ion diffusion for both 1 Ampere and control treatments ($P < 0.05$). At the higher level (0 vs 2 Amperes) of electrical current there was no effect due to time; however, a significant ($P < 0.038$, Table 28, Appendix) quadratic effect was observed for control samples due to higher chloride ion diffusion values at 16 hours

(1503.71 ppm, Table 4). This could be explained by the differences in the animals or differences in uncontrolled variables between the two experiments.

This study shows that there was approximately one and a half times increase in chloride ion diffusion due to electrochemical treatment for most of the time periods. This increase was more pronounced at the higher level of electrical current and near the anterior end of the LD muscle suggesting that increased diffusion took place under a modified electrochemical environment, as discussed earlier for nitrite diffusion.

Sodium Ion

Sodium ion concentration may be thought of as an index of the degree of diffusion of various sodium components used in curing solutions such as Sodium chloride, Sodium nitrate, Sodium isoascorbic acid and Sodium tripolyphosphate. Sodium ion data are presented in Tables 5 and 6.

The data analysis for the lower level of electrical current (0 vs 1 Ampere, Table 5) indicated no significant ($P > 0.05$, Table 29, Appendix) interactions between position and electrical current or any effect of position in the muscle on sodium ion diffusion at any time period. The effect of electrical current was significant ($P < 0.030$) only for the 22 hour treatment. The increase in sodium ion diffusion at 13, 16 and 22 hours was 7.8% ($P = 0.652$), 35.99% ($P = 0.056$) and 27.02% ($P = 0.030$), respectively.

Data analysis of the higher level of electrical current (0 vs 2

TABLE 5

SODIUM ION CONCENTRATION (PPM)[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 1 AMPERE)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average
		ppm	ppm	ppm	ppm
	A	728	779	1060	856
0	B	725	796	947	823
	C	711	793	1080	861
	Average	721	789	1029	846
	A	704	785	909	799
1	B	740	843	1188	924
	C	889	1589	1825	1434
	Average	777	1073	1307	1052

[a]Each value is the average of 6 observations.

TABLE 6

SODIUM ION CONCENTRATION (PPM)[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 2 AMPERES)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average
		ppm	ppm	ppm	ppm
0	A	970	949	900	940
	B	886	1006	850	914
	C	766	970	901	879
	Average	874	975	883	911
2	A	956	989	994	980
	B	924	999	792	905
	C	2497	2152	2834	2494
	Average	1459	1380	1540	1460

[a]Each value is the average of 6 observations.

Amperes, Table 6) showed significant interactions between electrical current and position ($P < 0.0001$, $P = 0.004$ and $P < 0.0001$ for 13, 16 and 22 hours, respectively, Table 29, Appendix). The effect of position in muscle was also significant ($P < 0.05$, Table 29, Appendix).

Comparison of the lower level (1 Ampere) and the higher level (2 Amperes) of electrical current treatment (Table I, Appendix) indicated significant interactions between position and electrical current ($P = 0.0001$). There was minimal effect at position B, somewhat higher effect for higher level of electrical current at position A and very large effect on the diffusion of sodium ions for 2 Amperes at position C.

Analysis of the time effect (Table 30, Appendix) on sodium ion diffusion showed significant linear effects for the lower level of electrical current and both the control samples ($P < 0.05$). On the other hand, the higher level of electrical current (0 vs 2 Amperes) exhibited a significant quadratic effect ($P < 0.038$, Table 30, Appendix) due to a lower sodium ion diffusion value for 16 hour samples (1380 ppm), compared to 1459 ppm and 1560 ppm for 13 and 22 hours, respectively (Table 6). Similar effects of time was observed for chloride ion diffusion as mentioned earlier and was attributed to differences in animals or differences in some unknown variables between the two experiments.

Therefore, this study showed that the application of electrochemical curing technology increased the overall sodium ion diffusion by about one and a half times for all time periods and electrical current levels (except the 2 Ampere, 16 hour treatment). The increase in diffusion was predominantly at the anterior end of the LD muscle. The

combined effects of a possible modification of phospholopid bilayers of meat tissue membranes and/or a more open microstructure of muscle at the anterior end as mentioned earlier for the higher diffusion of sodium nitrite and chloride ions.

Denatured Nitrosomyoglobin Pigment

Denatured nitrosomyoglobin pigment is responsible for the most desirable pinkish-red cured meat color. It is the most stable meat color in cured cooked meats. Denatured nitrosomyoglobin values are presented in Tables 7 and 8.

Analysis of variance of data from the lower level of electrical current treatment (0 vs 1 Ampere, Table 7) showed no significant interactions between position and time or time and electricity ($P > 0.05$, Table 31, Appendix). The effect of electrical current on denatured nitrosomyoglobin formation was -5.4% ($p = 0.894$), 11.4% ($P = 0.682$) and 22.0% ($P = 0.142$) for 13 16 and 22 hours, respectively.

The higher level of electrical current treatment (0 vs 2 Amperes, Table 8) data indicated no significant interactions between position and time or time and electricity ($P > 0.05$ Table 31, Appendix). Application of higher level of electrical current treatment (2 Amperes) increased denatured nitrosomyoglobin formation by 5.8% ($P = 0.791$) and 2.34 % ($P = 0.789$) for the 13 hour and 22 hour treatment, respectively, but decreased by 18.9% ($P = 0.747$) for the 16 hour treatment.

The analysis of data for the lower level (1 Ampere) versus the higher level (2 Amperes) of electrical current treatment resulted in nonsignificant interactions ($p > 0.05$, Table 23, Appendix) between

TABLE 7

DENATURED NITROSOMYOGLOBIN PIGMENT (PPM)[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 1 AMPERE)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average
		ppm	ppm	ppm	ppm
	A	9.57	22.99	16.19	16.25
0	B	9.33	14.69	15.08	13.03
	C	8.94	13.51	17.01	13.15
	Average	9.28	17.06	16.10	14.14
	A	9.52	14.23	12.71	12.15
1	B	8.94	13.57	12.52	11.68
	C	7.88	17.57	12.47	12.64
	Average	8.78	15.12	12.57	12.16

[a]Each value is the average of 6 observations.

TABLE 8

DENATURED NITROSOMYOGLOBIN PIGMENT (PPM)[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 2 AMPERES)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average
		ppm	ppm	ppm	ppm
0	A	15.52	11.71	12.81	13.34
	B	14.79	11.07	12.71	12.20
	C	15.61	12.68	11.65	12.20
	Average	15.31	10.71	12.39	12.58
2	A	13.92	13.15	11.89	12.99
	B	14.16	10.98	12.42	12.52
	C	15.18	14.06	11.99	13.74
	Average	14.42	12.73	12.10	13.08

[a]Each value is the average of 6 observations.

nonsignificant interactions ($p > 0.05$, Table 23, Appendix) between electrical current and position, position and time or time and electrical current.

All three positions indicated the highest effect at the 16 hour treatment. The minimal effect being at position B, somewhat higher at position A and the highest effect was noticed at position C (anterior end of LD). Since denatured nitrosomyoglobin formation is a function of available sodium nitrite in the cured meat color fixing reaction, this observation agrees with previous results showing a higher sodium nitrite diffusion at position C.

Curing time data analysis (Table 32, Appendix) showed that as the curing time was increased, the denatured nitrosomyoglobin formation was also increased significantly in a linear fashion ($P < 0.05$) in the control samples of lower level of electrical current treatment but the electrochemically treated samples resulted in a significant quadratic effect ($P = 0.003$) due to a higher value in 16 hour samples (Table 8). The higher level of electrical current (2 Amperes) showed similar results as that of the lower level of electrical current for control samples but electrochemically treated samples failed to show any effect over time (Table 32, Appendix).

Total Pigment

Total pigment is composed of hematin derived from any uncombined pigment present together with those resulting from the oxidation of nitric oxide pigment. Total pigment data are presented in Tables 9 and 10.

Lower level of electrical current treatment (0 vs 1 Ampere) data

are presented in Table 9. The analysis of variance (Table 33, Appendix) showed no significant interactions between position and electrical current ($P > 0.05$) or any effect of position in the muscle ($p > 0.05$). The effect of electrical current also was not significant ($P = 0.368$, Table 33, Appendix). The effect of electrical current on total pigment formation was 6.08% ($P = 0.605$), -15.39% ($P = 0.368$) and 2.85% ($P = 0.490$) for 13, 16, and 22 hours, respectively.

No significant interactions resulted ($P > 0.05$, Table 33, Appendix) from the application of the higher level of electrical current (0 vs 2 Amperes, Table 10). Table 33 (Appendix) also revealed no significant effects of position in the muscle ($P > 0.05$).

The effect of the higher level (0 vs 2 Amperes) of electrical current on total pigment formation was 0.05% ($P = 0.984$), 7.88% ($P = 0.856$) and -10.15% ($P = 0.436$) for 13, 16 and 22 hours, respectively. However, a comparison of the electrochemically cured samples only showed significantly reduced ($P < 0.016$, Table 34, Appendix) total pigment formation with increased curing time.

A comparison of the lower versus the higher level of electrical current data (Table 23, Appendix) showed no significant effects ($P > 0.05$) of time, electrical current or position in the muscle. The overall effect of electrical current was 9.43%, 11.37% and -21.81% for 13, 16 and 22 hours, respectively.

Cured Color Area

The area of color fixation by nitric oxide in cured cooked meat appears as pinkish-red and may be called the cured color area. It is a

TABLE 9

TOTAL PIGMENT VALUE (PPM)[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 1 AMPERE)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average
		ppm	ppm	ppm	ppm
	A	44.40	46.99	47.49	46.29
0	B	39.68	45.43	38.76	41.29
	C	41.25	46.97	45.22	44.48
	Average	41.77	46.46	43.82	44.02
	A	48.17	37.96	45.22	43.78
1	B	41.50	40.36	44.20	41.92
	C	43.25	39.63	45.79	42.89
	Average	44.31	39.31	45.07	42.90

[a]Each value is the average of 6 observations.

TABLE 10

TOTAL PIGMENT VALUE (PPM)[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 2 AMPERES)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average
		ppm	ppm	ppm	ppm
0	A	47.51	46.67	37.66	43.95
	B	45.67	42.39	36.61	41.56
	C	51.79	32.91	43.41	42.70
	Average	48.23	40.59	39.22	42.74
2	A	48.26	45.33	38.99	44.19
	B	50.33	41.03	36.95	42.77
	C	46.86	44.90	29.77	40.54
	Average	48.49	43.78	35.24	42.50

[a]Each value is the average of 6 observations.

visual index of cured color formation in cured cooked meat. The cured color area values are presented in tables 11 and 12.

Analysis of the lower level of electrical current treatment values (0 vs 1 Ampere, Table 11) indicated only the effect of position in the muscle was significant ($P < 0.014$, Table 35, Appendix). This appeared to be due to the higher cured color area at position C. The overall effect of the lower level of electrical current treatment resulted in 2.3% ($P = 0.714$), 4.9% ($P = 0.390$) and -0.9% ($P = 0.923$) cured color area for 13, 16 and 22 hours, respectively.

Cured color area values for the higher level of electrical current treatment (0 vs 2 Amperes, Table 12) showed no significant interactions between position and electrical current ($P > 0.05$, Table 35, Appendix); the above table (Table 35) also indicated that there was no significant effect of either electrical current or position. The effect of electrical current was 5.8% ($P = 0.371$), 25.3% ($P = 0.051$) and 0.4% ($P = 0.147$) for 13, 16, and 22 hours, respectively.

A comparison of the data from the lower (1 Ampere) versus the higher level (2 Amperes) of electrical current treatment (Table 24, Appendix) resulted in no significant interactions between position and electrical current, position and time or position, electricity and time ($P > 0.05$); however, a significant effect was observed for time and electrical current ($P < 0.05$). The effect of electrical current was least at position B, somewhat higher at position A and decidedly greater at position C except at 13 hours.

Cured Color Intensity (L-value)

The cured color intensity may be represented by L-value. The L-

TABLE 11

CURED COLOR AREA (PERCENT)[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 1 AMPERE)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average
		%	%	%	%
0	A	91.50	87.11	100.00	92.87
	B	83.46	83.46	98.62	88.51
	C	94.17	100.00	98.18	97.45
	Average	89.71	90.32	99.93	92.94
1	A	90.26	92.52	98.75	93.84
	B	84.65	91.76	99.05	91.82
	C	88.05	99.86	99.43	95.78
	Average	87.65	94.72	99.08	93.82

[a]Each value is the average of 6 observations.

TABLE 12

CURED COLOR AREA (PERCENT)[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 2 AMPERES)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average
		%	%	%	%
0	A	90.85	91.49	100.00	94.11
	B	85.86	83.46	100.00	89.77
	C	98.65	64.17	100.00	87.61
	Average	91.79	79.71	100.00	90.50
2	A	100.00	100.00	99.62	99.87
	B	91.36	99.63	99.43	96.81
	C	100.00	100.00	99.69	99.90
	Average	97.12	99.88	99.57	98.86

[a]Each value is the average of 6 observations.

value is a measure of diffused reflectance. In general, the higher the L-value, the brighter is the color and vice versa. The L-values are presented in Tables 13 and 14.

The L-value data for the lower level of electrical current treatment (0 vs 1 Ampere, Table 13) resulted in no significant interactions between position and electrical current ($P > 0.05$, Table 37, Appendix), and no significant position effects but the electrical current effect was significant at 16 hours, only ($P = 0.022$). The overall effect of electrical current was -2.5% ($P = 0.133$), -5.1% ($P = 0.022$) and 11.6% ($P = 0.412$) for 13, 16, and 22 hours, respectively. Both positions A and B had approximately similar L-values and position C had slightly higher values except for the 13 hour group.

At the higher level of electrical current treatment (0 vs 2 Amperes, Table 14), the analysis of variance resulted in no significant interactions ($P > 0.05$, Table 37, Appendix) between position and electrical current. The effect of electrical current was 0.8% ($P = 0.964$), -2.4% ($P = 0.551$) and 2.3% ($P = 0.746$) for 13, 16 and 22 hours, respectively. All three positions had more or less similar average L-values suggesting no position effect. Both control and treated samples indicated a significantly linear increase ($P < 0.0001$, Table 38, Appendix) of L-values with increased curing time.

Comparison of the higher and the lower level of electrical current treatment (Table 23, Appendix) resulted in no significant ($P > 0.05$) interactions of position and electrical current, position and time, time and electrical current or position, time, and electrical current. Position A at 22 hours had the brightest cured color and position C at

TABLE 13

CURED COLOR INTENSITY (L-VALUE)[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 1 AMPERE)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average[b]
0	A	69.14	67.50	71.27	69.30
	B	71.22	67.03	71.20	69.84
	C	69.03	76.25	72.63	72.64
	Average	69.79	70.26	71.70	70.59
1	A	70.47	64.65	80.16	71.76
	B	69.10	66.82	78.34	71.42
	C	64.56	68.53	81.47	71.51
	Average	68.04	66.66	79.99	71.56

[a]Each value is the average of 6 observations.

TABLE 14

CURED COLOR INTENSITY (L-VALUE)[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 2 AMPERES)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average[b]
0	A	55.12	69.64	73.45	66.08
	B	54.90	68.76	78.91	67.52
	C	55.41	67.87	83.06	68.88
	Average	55.24	68.76	78.47	67.49
2	A	56.32	66.11	80.50	67.64
	B	55.96	67.61	76.39	66.65
	C	54.79	67.69	73.02	65.17
	Average	55.69	67.14	76.64	66.49

[a]Each value is the average of 6 observations.

13 hours had the least.

Moisture Content

Moisture content of cured meat is a very important quality attribute because it is directly related to water holding capacity, processing yield, texture and palatability. Moisture content values are presented in Tables 15 and 16.

The lower level of electrical current treatment (0 vs 1 Ampere, Table 15) data analysis resulted in no significant ($P > 0.05$, Table 39, Appendix) interactions between position and electrical current or the effect of electrical current, only. The average effect of electrical current was 1.6% ($P = 0.231$, 5.3% ($P = 0.256$) and 0.8% ($P = 0.596$) for 13, 16 and 22 hours, respectively. Position C had the highest moisture content at 16 hours (74.4%) and position A had the least at 22 hours (68.5%). As the curing time was increased from 13 to 16 hours both control and treated samples showed an increase (Table 15) but there were decreased values when the curing time was increased to 22 hours showing a significant quadratic effect for both control and treated samples ($P < 0.05$ Table 40, Appendix) due to some unexplained factors.

At the higher level of electrical current, (0 vs 2 Amperes, Table 16) the analysis of variance showed no significant interactions between electrical current and position ($P > 0.05$, Table 39, Appendix). The effect of electrical current was -0.0% ($P = 0.394$), 0.8% ($P = 0.690$) and 2.1% ($P = 0.381$) for 13, 16, and 22 hours, respectively. Position C of electrochemically treated muscles at 22 hours had the highest average value (72.7%) and the same position at 13 hour treatment showed

TABLE 15

MOISTURE CONTENT (PERCENT)[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 1 AMPERE)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average
		%	%	%	%
0	A	69.03	70.20	68.27	69.17
	B	69.00	70.43	68.63	69.35
	C	68.37	71.30	68.43	69.37
	Average	68.80	70.64	69.56	69.30
1	A	69.33	71.03	68.47	69.61
	B	70.30	71.20	70.07	70.52
	C	69.98	74.37	70.14	71.50
	Average	69.87	72.20	69.56	70.55

[a]Each value is the average of 6 observations.

TABLE 16

MOISTURE CONTENT (PERCENT)[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 2 AMPERES)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average
		%	%	%	%
0	A	69.61	70.09	69.28	69.66
	B	70.00	69.41	70.48	69.96
	C	70.10	69.65	70.52	70.90
	Average	69.30	69.72	70.02	69.90
2	A	68.28	70.58	70.90	69.92
	B	70.23	69.94	71.90	70.59
	C	69.38	71.00	72.09	70.82
	Average	69.30	70.51	71.52	70.44

[a]Each value is the average of 6 observations.

the least moisture content (69.7%). As the curing time was increased, the moisture content also increased significantly ($P < 0.01$, Table 40, Appendix) in a linear fashion.

A comparison of the lower level (1 Ampere) versus the higher level (2 Amperes) of electrical current, data analysis indicated no significant interactions ($P > 0.05$, Table 24, Appendix) between electrical current and position, electrical current and time, position and time or position, time and electrical current, however, a significant position effect ($P < 0.004$) was observed due to high values at position C for 16 and 22 hours. The overall effect of electrical current was -0.8%, -2.3% and 3.6% for 13, 16 and 22 hours, respectively.

Juiciness (Pressed Fluid Ratio)

The water holding capacity of cured meat can be measured by the quantity of meat juice present. Juiciness was measured by pressed fluid ratio. Pressed fluid ratio can be viewed using two criteria. The larger the ratio, the more juicy the product (Cagle, 1969) or larger the ratio the less water holding capacity of the meat (Syre et al, 1963). The pressed fluid ratio values are presented in Tables 17 and 18.

Application of the lower level of electrical current (0 vs 1 Ampere) resulted in no significant ($P > 0.05$, Table 41, Appendix) interactions between electrical current and position. The effect of electrical current on juiciness was 2.0% ($P = 0.889$), -3.8% ($P = 0.686$) and 8.9% ($P = 0.541$) for 13, 16 and 22 hours, respectively. The juiciest meat resulted from position C at 22 hours and the least juicy

TABLE 17

JUICINESS (PRESSED FLUID RATIO)[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 1 AMPERE)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average
0	A	5.37	5.94	5.57	5.63
	B	6.20	5.70	6.35	6.08
	C	5.18	5.53	6.40	5.70
	Average	5.58	5.73	6.10	5.80
1	A	5.81	5.20	6.40	5.80
	B	5.70	6.20	6.74	6.21
	C	5.56	5.14	6.78	5.83
	Average	5.69	5.51	6.64	5.74

[a]Each value is the average of 6 observations.

TABLE 18

JUICINESS (PRESSED FLUID RATIO)[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 2 AMPERES)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average
0	A	5.07	7.35	7.45	6.62
	B	5.34	6.62	8.21	6.72
	C	5.34	5.40	7.19	5.98
	Average	5.25	6.45	7.62	6.44
2	A	5.17	7.28	6.25	6.23
	B	4.78	8.32	7.34	6.81
	C	4.88	5.10	6.98	5.65
	Average	4.94	6.90	6.85	6.23

[a]Each value is the average of 6 observations.

meat was observed at position C at 13 hours. As the curing time was increased the electrochemical treatment increased juiciness significantly ($P < 0.05$, Table 42, Appendix).

The higher level of electrical current treatment data (0 vs 2 Amperes, Table 18) analysis did not result in any significant interactions between electrical current and position ($P < 0.05$, Table 41, Appendix). The effect of electrical current was -5.9% ($P = 0.126$), 7.0% ($P = 0.610$) and -0.1% ($P = 0.288$) for 13, 16, and 22 hours, respectively. Position B was the most juicy at 16 hours and position C was the least juicy at 13 hours. As the curing time was increased both the control and electrochemically cured samples showed significant linear increases in juiciness ($P < 0.05$, Table 42, Appendix).

Comparison of the data from the higher level (2 Amperes) and the lower level (1 Ampere) of electrical current treatment (Table 24, Appendix) resulted in no significant interactions ($P > 0.05$) between position and electrical current, position and time, time and electrical current or time, position and electrical current. However, Table 24 shows significant position effects ($P < 0.05$) due to higher values for position B at 16 hours. The overall effect of electricity was 13.2%, 25.2% and 3.2% for 13, 16 and 22 hours, respectively.

Tenderness (Warner-Bratzler Shear Value)

Cured cooked meat tenderness may be estimated by measuring the shear force needed to cut a piece of meat. Meat tenderness varies inversely as the amount of shear force needed to cut a defined piece of meat. In this study, a Warner-Bratzler shear apparatus was used to

obtain tenderness values. The tenderness values (Warner-Bratzler Shear Value) are presented in Tables 19 and 20.

Analysis of variance of the lower level of electrical current treatment (0 vs 1 Ampere, Table 19) indicated no significant interactions between electrical current and position ($P > 0.05$, Table 43, Appendix). The same table (Table 43) also showed no significant position or electrical current effects. On the average, position A appeared to be the most tender and position C had the toughest (least tender) meat. At 22 hours, position C had the most tender meat. Most probably this is due to increased protein denaturation at position C under a prolonged exposure to the electrochemical environment.

The higher level of electrical current treatment data (0 vs 2 Amperes, Table 20) analysis did not result in any significant interactions between electrical current and position ($P > 0.05$, Table 43, Appendix). The effect of electrical current on tenderness was -5.6% ($P = 0.603$), -6.5% ($P = 0.714$) and -0.2% ($P = 0.984$) for 13, 16, and 22 hours respectively. The position effect comparison failed to show significant results (Table 43, Appendix). Position A had the most tender meat at 22 hours and position B had the least tender meat at 16 hours. As the curing time was increased from 13 to 16 hours both control and electrochemically cured meat tenderness decreased. However, both groups indicated increased tenderness at 22 hours producing a significant quadratic effect ($P < 0.05$, Table 44, Appendix).

A comparison of the higher level (2 Amperes) of electrochemical treatment versus the lower level (1 Ampere) data analysis resulted in

TABLE 19

TENDERNESS (WARNER-BRATZLER SHEAR VALUE)[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 1 AMPERE)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average
0	A	23.93	16.57	16.45	18.98
	B	23.45	18.37	18.30	20.04
	C	25.47	18.20	14.88	19.52
	Average	24.28	17.71	16.55	19.51
1	A	22.02	15.47	18.48	18.66
	B	24.20	18.82	16.53	19.85
	C	29.53	21.65	15.68	22.09
	Average	25.25	18.44	16.90	20.20

[a]Each value is the average of 6 observations.

TABLE 20

TENDERNESS (WARNER-BRATZLER SHEAR VALUE)[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 2 AMPERES)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average
0	A	20.48	17.33	15.85	17.89
	B	19.28	28.61	18.57	22.15
	C	20.75	23.78	19.07	21.20
	Average	20.17	23.24	17.83	20.41
2	A	16.83	18.88	15.51	17.08
	B	21.62	22.40	18.42	20.82
	C	18.67	23.90	19.45	20.67
	Average	19.04	21.72	17.79	19.52

[a]Each value is the average of 6 observations.

no significant interactions between position and electrical current, position and time, time and electrical current or position, time and electrical current ($P > 0.05$, Table 24, Appendix). The main effect of position was significant ($P = 0.006$) due to higher values at 16 and 22 hours.

Cooked Meat pH

Many pre- and postmortem factors affect the final meat pH. Since the pH of cooked meat affects flavor, taste and shelf life, it is a good process index. Cooked meat pH data are provided in Tables 21 and 22.

At the lower level (0 vs 1 Ampere, Table 21) of electrical current treatment, the data analysis reflected no significant interactions between electrical current and position ($P > 0.05$, Table 44, Appendix). The effect of electrical current was -0.6% ($P = 0.858$), -1.6% ($P = 0.562$) and -1.0% ($P = 0.813$) for 13, 16, and 22 hours, respectively. Position A showed the maximum effect of electrical current and position B had the least effect.

Analysis of data for the higher level of electrical current (0 vs 2 Amperes, Table 22) indicated no significant interactions of position and electrical current. The effect of electrical current was -2.1% ($P = 0.073$), -0.4% ($P = 0.929$) and 2.2% ($P = 0.395$) for 13, 16 and 22 hours. Again, position A showed the most effect and position B showed the least effect.

Comparison of the data from the higher level (2 Amperes) versus the lower level (1 Ampere) of electrical current treatment indicated significant interactions between time and electrical current ($P <$

0.012, Table 24, Appendix). The main effect of time was also significant (P = 0.0003, Table 24, Appendix) due to higher values of 1 Ampere--13 hour samples.

At position A the effect of electrical current was -3.7%, -11.3% and -19% for 13, 16 and 22 hours, respectively. At position B the effect of electrical current was -0.6%, 13.0% and -9.2% for 13, 16, and 22 hours, respectively. At position C the electrical current effect was -4.9%, 18.6% and -10.7%, respectively. On the average, the effect of electrical current was -3.3%, 14.4% and 2.2% for 13, 16 and 22 hours, respectively.

Average Voltage Change

Resistance to electricity flow is defined as voltage. In an electrochemical meat curing system, the resistance to electricity flow will be due to the meat, water molecules and undissociated ingredients (molecules) such as sodium chloride, sodium phosphate, sugar, isoascorbic acid and sodium nitrite etc. in the curing solution. The average voltage change of curing solution pH during electrochemical curing of porcine LD muscle is presented in Figure 3.

On the average both levels of electrical current data show some drop in the first four hours. This could be due to lower resistance provided by the undissociated solutes present in the curing solution. On the 6th hour, the resistance increased in the 1 Ampere curing solution and the rate of decrease was somewhat slower in the 2 Ampere curing solution indicating a more rapid onset of a dissociation process of the solutes in curing solution. There was lower resistance starting

TABLE 21

COOKED MEAT pH[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 1 AMPERE)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average
		pH	pH	pH	pH
0	A	4.90	4.51	4.22	4.54
	B	4.86	4.34	4.16	4.45
	C	4.77	4.47	4.08	4.44
	Average	4.84	4.44	4.15	4.48
1	A	4.81	4.44	4.16	4.47
	B	4.72	4.38	4.89	4.39
	C	4.88	4.30	4.68	4.42
	Average	4.81	4.37	4.11	4.30

[a]Each value is the average of 6 observations.

TABLE 22

COOKED MEAT pH[a] AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE (0 VS 2 AMPERES)

Electricity (Ampere)	Position in the Muscle	Hours of Curing 13	16	22	Average
		pH	pH	pH	pH
0	A	4.80	5.02	3.94	4.58
	B	4.76	4.95	4.32	4.69
	C	4.68	5.10	4.07	4.62
	Average	4.75	5.02	4.11	4.63
2	A	4.63	4.94	3.97	4.51
	B	4.69	4.95	4.44	4.70
	C	4.64	5.10	4.18	4.64
	Average	4.65	5.00	4.20	4.62

[a]Each value is the average of 6 observations.

from the 8th hour and it continued for 10 hours indicating a smooth electrical flow. In the last 6 hours, both 1 and 2 Ampere curing solution showed increased resistance. This could be due to some disintegrated fine meat protein molecules dispersed in the curing solution. These fine meat particles formed a clear visible track around the LD muscle following the electromagnetic field, similar to that of the orientation of iron dust around a magnetic bar. This type of orientation of meat particles around the LD muscle could create some extra resistance to the flow of electrical current resulting in a higher voltage during the last 6 hours.

Average Curing Solution pH Change

The average change in curing solution pH was more or less similar for both levels of electrical current treatment for the first eight hours ($\tilde{=}$ 10.35) as shown in figure 4.

The 1 Ampere curing solution pH continued to increase further to reach 11.06 in the last hour (except for a drop in the 16th hour). The 2 Ampere curing solution, on the other hand, reached to 10.48 in the 12th hour, then slowly dropped during the following hours to reach 9.88 in the 18th hour. There was a slight increase in the last four hours and the finishing pH was 10.1. The observed lower pH during the higher electrical current treatment indicates a more acidic environment. Such a situation might have caused more nitrosomyoglobin pigment formation in treated samples. Both the control samples had similar pH changes ($\tilde{=}$ 8 $\pm$0.2) during this study.

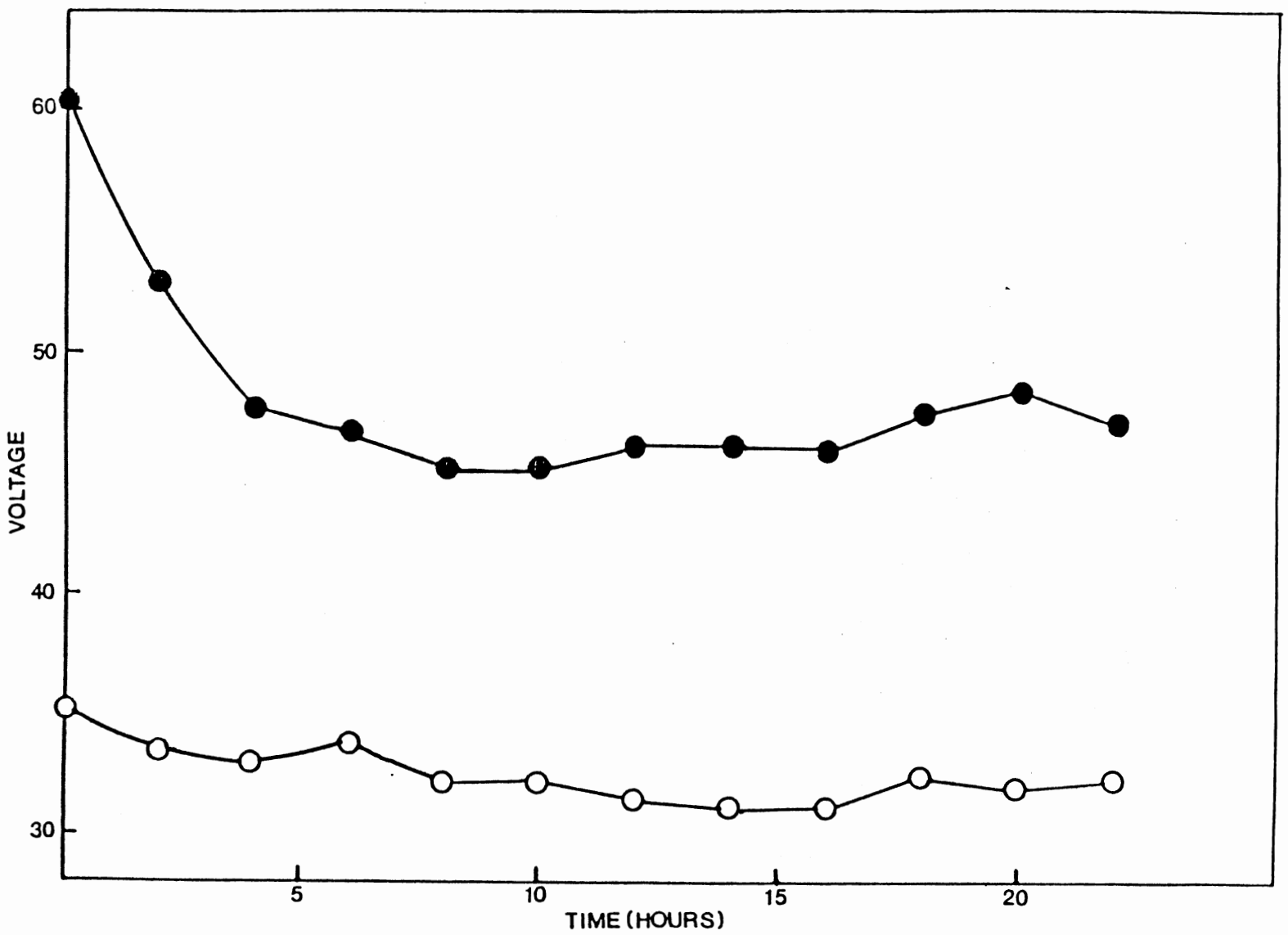

Figure 3. Average voltage change of curing solution during electrochemical curing at 1 Ampere (O) and 2 Amperes (●).

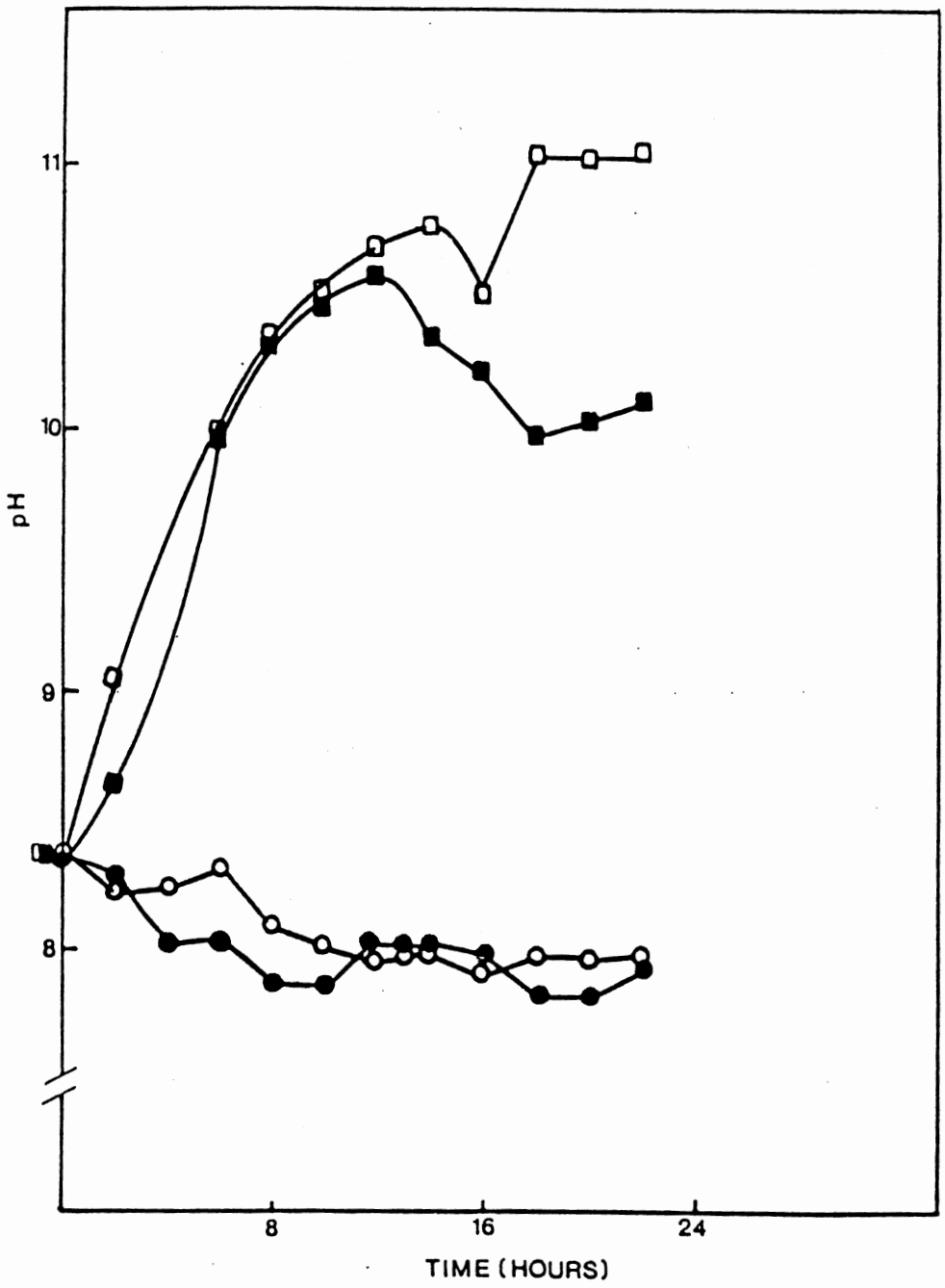

Figure 4. Average curing solution pH change of 1 Ampere control (○), 1 Ampere treated (□), 2 Ampere control (●) and 2 Ampere treated (■) samples during electrochemical curing.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Experimental muscles were obtained from the left and right loins of 18 market weight hogs and the Longissimus dorsi (LD) muscle was excised from each loin between the 8th thoracic vertebra and the sacroiliac joint at 24 hours post-mortem. Most of the knife trimable fat was removed and diffusion of curing ingredients was allowed to take place in a rectangular plexiglass tank equipped with two carbon electrodes partially immersed into the curing solution and connected to a DC power supply. Treatment combinations involved 2 levels of electrical current (1 and 2 amperes) and 3 levels of time (13, 16, and 22 hours).

After electrochemical curing, the muscles were cooked, cooled and analyzed for the following physicochemical cured meat quality characteristics: residual sodium nitrite, chloride ions, sodium ions, denatured nitrosomyoglobin, total pigment, cured color area, cured color intensity, juiciness, tenderness, cooked meat pH and moisture content.

Application of electrochemical curing technology significantly ($P<0.05$) increased sodium nitrite diffusion with higher level of electrical current (2 amperes) and prolonged curing time (in most cases) at the anterior end of porcine LD muscle. Both chloride and sodium ions diffusion were increased by approximately one and a half times with increased electrical current level, prolonged curing time and proximity

of meat tissue towards the anterior end of LD muscle. Denatured nitrosomyoglobin pigment and total pigment were not affected by the level of electrical current, time of curing or proximity of meat tissue towards the anterior end of the LD muscle. The area of color fixation (cured color area) was slightly higher at the lower curing time but this difference disappeared with increased curing time.

Electrochemical curing did not improve the cured color intensity (L values), juiciness or tenderness. There was no significant ($P>0.05$) effect of electrical current level or position in the muscle on cooked meat pH. There was a significant ($P<0.001$) decrease in the cooked meat pH values as the curing time was increased (16 hours and 22 hours). Moisture content was somewhat increased and in some cases the increase was statistically significant ($P<0.05$).

Both 1 ampere and 2 amperes of electrical current treatment curing solution indicated a voltage drop during the first four hours of curing suggesting rapid dissociation of curing agents during the beginning four hours and then remained approximately the same during rest of the curing period indicating less or no dissociation. The curing solution pH for 1 ampere was higher at the beginning and continued to increase with increased time except a drop at the 16th hour. On the other hand, 2 amperes curing solution had an initial lower curing solution pH which reached its peak at the 12th hour then slowly dropped during rest of the curing period.

The study has shown that the application of electrochemical curing technology can increase the diffusion of nitrite, chloride and sodium ions and moisture content in porcine LD muscle. The increase was more

pronounced at the anterior end of the LD muscle than the posterior end or middle. This was attributed to more open microstructure of meat tissue near the anterior end. Also, there might be a modification of phospholipid bilayers of the meat tissue membranes due to the release of charged molecules from the dissociation of curing ingredients or a combination of these two factors could play some important roles to increase membrane permeability and accelerate the diffusion of nitrite, chloride and sodium ions. Additional research work is needed, however, to substantiate such a proposition.

LITERATURE CITED

Addis, P. B. and Schanus, E. S., 1979. Massaging and tumbling in the manufacture of meat products. J. Food Sci. 44:36.

A.O.A.C. 1984 "Official Methods". Association of Official Analytical Chemists. 14th Edition. Washington, D.C., U.S.A.

Birdsall, J. J., 1979. Update on nitrite safety. Proceedings of the meat Industry Research Conference, Chicago, Illinois, USA. p. 75.

Buchowsky, M. S., Mahony, A. W., Carpenter, C. E. and Cornforth, D. P., 1988. Heating and the distribution of total and heme iron between meat and broth. J. Food Sci. 53:43.

Cagle, E. D. and Henrickson, R. L., 1970. Influence of slicing warm porcine muscle on fiber diameter, kinkiness and shear force. J. Food Sci. 35:270.

Cassens, R. G., Greaser, M. L., Ito, T. and Lee, M., 1979. Reactions of nitrite in meat. Food Technol. 33 (7):46.

Dreano, C. and Noyelle, A., 1980. United States Patent 4,229,458.

Dryden, F. D. and Birdsall, J. J., 1980. Why nitrite does not impart color. Food Technol. 34 (8):29.

Dymicky, M., Fox, J. B. and Wasserman, A. E., 1975. Color formation in cooked model and meat systems with organic and inorganic compounds. J. Food Sci. 40:306.

Ford, A. L., Jones P. N., Macfarlane, J. J., Schmidt, G. R. and Turner, R. H., 1978. Binding of meat pieces: Objective and subjective assessment of restructured steakettes containing added myosin and/or sacroplasmic protein. 43:815.

Fox, J. B., 1966. The chemistry of meat pigments. J. Agric. Food Chem. 14:207.

Fujimaki, M., Emi, M., Okitani, A., 1975. Fate of nitrite in meat-curing model systems composed of myoglobin, nitrite and ascorbate. Agri. Biol. Chem. 39 (2):371.

Gelpi, A. J. Jr. and Devreux, E. D. 1930. Effect of the electro-pure process and the holding method of treating milk upon bacterial

endospores. J. Dairy Sci. 13:368.

George, A. R., Beudal, J. R. and Jones, R. C. D. 1980. The tenderizing effect of electrical stimulation of beef carcasses. Meat Sci. 4:51.

Giddings, G. G., 1977. The basis of color in muscle foods. J. Food Sci. 42:288.

Goutefonegea, R., Cassens, R. G. and Woolford, G., 1977. Distribution of sodium nitrite in adipose tissue during curing. J. Food Sci. 42:1637.

Herring, H. K., 1973. Effect of nitrite and other factors on the physicochemical characteristics and nitrosamine formation in bacon. Proceedings of the Meat Industry Research Conference--American Meat Institute Foundation. Chicago Ill. p.47.

Hornsey, H. C. 1956. The Color of cooked cured pork. 2. Estimation of the nitric oxide-haem pigments. J. Sci. Food Agric. 7:534.

Krause, R. J., Plimpton, R. F., Ockerman, H. W. and Cahill, V. R., 1978. Influence of tumbling and sodium tripolyphosphate on salt and nitrite distribution in porcine muscle. J. Food Sci. 43:190.

Lee, K. and Shimaoka, J. E., 1984. Forms of iron in meats cured with nitrite and erythorbate. J. Food Sci. 49:284.

Lee, S. H. and Cassens, R. G., 1976. Nitrite binding sites of myoglobin. J. Food Sci. 41:969.

Medeiros, L. C., Field, R. A., Medeiros, D. M. and Russell, W. C., 1988. Effect of altitude and management system on the iron content of beef. J. Food Sci. 53:37.

Mizrahi, S., Kopelman, I. J. and Perlman, J. 1975. Blanching by electro-conducting heating. J. Food Technol. 10:281.

Ockerman, H. W. and Organisciak, C. S., 1978. Diffusion of curing brine in tumbled and non-tumbled porcine tissue. J. Food Protect. 41:178.

Ockerman, H. W. and Dowiercial, R., 1980. Influence of tumbling and electrical stimulation on distribution and content of sodium nitrite and sodium chloride in bacon. J. Food Sci. 45:1301.

Ockerman, H. W., Plimpton Jr., R. F., Cahill, V. R. and Parrett, N. A., 1978. Influence of short term tumbling, salt and phosphate on cured canned pork. J. Food Sci. 43:878.

Oelingrath, I. M., 1988. Heat degradation of heme in methemoglobin model systems measured by reversed-phase ion-pair high performance liquid chromatography. J. Food Sci. 53:40.

Orion Research. 1980. Orion application information: Measurement procedure by electrode. Procedure No. 204: Salt in Processed Meats. Cambridge, Massachusetts, U. S. A.

Reynolds, J. B., Anderson, D. B., Schmidt, G. R., Theno, D. M. and Seigel, D. G., 1978. Effects of ultrasonic treatment on binding strength in cured ham rolls. J. Food Sci. 43:866.

Rust, R. E. and Olson, D. G., 1973. Meat curing principles and modern practices, Koach Supplies Inc., Kansas City, Missouri, U. S. A.

SAS Institute Inc., 1985. SAS Circle, P. O. Box 8000, Cary, North Carolina 27511-8000, U. S. A.

Seigel, D. G., Theno, D. M., Schmidt, G. R. and Norton, H. W., 1978. Meat massaging. The effect of salt, phosphate and massaging on cooking loss, binding strength and exudate composition in sectioned and formed ham. J. Food Sci. 43:331.

Steel, R. G. D. and Torie, J. H. 1980. Principles and practices of statistics--A biochemical approach. 2nd Ed. McGraw Hill Book Company, New York, U. S. A.

Stryer, L., 1975. Biochemistry. W. H. Freeman and Company, San Fransisco, California, U.S.A.

Syre, R. N. and Brinsky, E. J. 1963. Protein solubility as influenced by physiological conditions in the muscle. J. Food Sci. 28:675.

Tarladgis, B. G., 1962. Interpretation of the spectra of meat pigments. 1. Cooked meats. J. Sci. Food Agric. 13:481.

Thompson, J. T. 1976. The effect of electrical current on hot boned pork quality. M. S. Thesis in Food Science, Graduate College, Oklahoma State University, Stillwater, Oklahoma, U. S. A.

Weiss, G. M., 1974. Ham tumbling and massaging. Western Meat Ind. Special reprint.

Woolford, G., Cassens, R. G., 1977. The fate of sodium nitrite in bacon. J. Food Sci. 42:588.

Woolford, G., Cassens, R. G., Greaser, M. L. and Sebranek, J. G., 1976. The fate of nitrite: Reaction with protein. J. Food Sci. 41:585.

APPENDIXES

TABLE 23

ANALYSIS OF VARIANCE OF SOME CHEMICAL AND PHYSICAL CHARACTERISTICS OF CURED MEAT AS AFFECTED BY ELECTRICAL CURRENT LEVEL[a], CURING TIME[b] AND POSITION[c] IN MUSCLE

Source of Variation	d.f[d].	Mean Squares: Sodium nitrite	Chloride ions	Sodium ions	Nitroso-myoglobin	Total pigment	color L
Total	53						
Electricity (E)	1	4298.73**	5321923**	2238146**	11.58	2.11	338.05
Time (T)	2	842.01	1026922	431874	25.41	193.32	1273.22
T x E	2	4000.81**	619155	260387	79.07	300.74	200.47
Error (a)	12	464.85	329839	138714	32.33	210.47	1171.47
Position (P)	2	32453.71***	16111498***	6775727***	5.41	24.48	10.03
P x E	2	7854.91**	3522186***	1481264***	0.11	12.97	8.16
P x T	4	385.58	328102	137984	6.92	12.15	21.09
P x E x T	4	624.83	385130	161967	2.85	38.57	16.28
Error (b)	24	961.13	284772	119761	4.85	40.92	22.62

d.f. = Degrees of freedom; a = 1 ampere versus 2 ampere; b = 13 hours, 16 hours and 22 hours; c = Anterior, middle or posterior; d = Total d. f. for color L is 50 and Error (b) is 22;
*, **, *** Significant at P<0.05, 0.01, and 0.001, respectively.

TABLE 24

ANALYSIS OF VARIANCE OF COOK pH, JUICINESS (PRESSED FLUID RATIO), MOISTURE CONTENT, TENDERNESS (WARNER BRATZLER SHEAR VALUE) AND CURED AREA AS AFFECTED BY ELECTRICAL CURRENT LEVEL[a], CURING TIME[b] AND POSITION[c] IN MUSCLE.

Source of Variation	d.f[d].	Mean Squares				
		Cook pH	Juiciness	Moisture	Tenderness	Cured Area
Total	53					
Electricity (E)	1	0.47	1.10	0.18	6.19	343.38*
Time	2	1.84***	9.41*	13.87	104.30	229.35*
T x E	2	0.72*	5.14	16.01	109.70	90.48
Error (a)	12	0.11	2.09	6.29	30.40	57.62
Position (P)	2	0.01	2.75	8.57**	58.62**	59.62
P x E	2	0.02	0.75	1.27	9.14	4.13
P x T	4	0.09	2.55	2.86	10.37	30.30
P x E x T	4	0.04	0.89	1.53	18.10	17.45
Error (b)	24	0.03	1.62	1.22	9.30	30.45

d.f. = Degrees of freedom; a = 1 ampere versus 2 ampere; b = 13 hours, 16 hours and 22 hours; c = Anterior, middle or posterior; d = Total d. f. for color L is 50 and Error (b) is 22; *, **, *** Significant at $P<0.05$, 0.01, and 0.001, respectively.

TABLE 25

ANALYSIS OF VARIANCE OF RESIDUAL SODIUM NITRITE AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE

Source of Variation	d.f.	Mean Squares					
		0 Vs 1 Ampere			0 Vs 2 Amperes		
		13H	16H	22H	13H	16H	22H
Total	17						
Electricity (E)	1	843.92*	1957.29	5468.84**	8901.34***	6412.78	2753.81
Error (a)	4	52.52	821.91	112.67	110.05	1098.15	532.17
Position (P)	2	165.79	920.54	1938.32	6279.64***	4643.92**	5938.77***
E x P	2	207.69	1121.90	1959.73	8017.04***	5048.58***	6577.11***
Error (b)	8	218.78	815.78	2010.99	162.11	272.55	24.75

d.f. = Degrees of freedom

H = Time of Curing (hours).

*, **,*** Significant at $P<0.05$, 0.01, and 0.001, respectively.

TABLE 26

ANALYSIS OF VARIANCE OF RESIDUAL SODIUM NITRITE AS AFFECTED BY TIME (HOURS) OF CURING

Source of Variation	d.f.	Mean Squares			
		1 Ampere		2 Amperes	
		Control	Treated	Control	Treated
Total	26				
Time[1]	1	1808.24***	7779.20*	98.41	1066.00
Time[2]	1	11.35	106.06	753.62	734.43
Error	24	112.61	1592.87	205.33	3280.11

d.f. = Degrees of freedom

[1]Linear time relationship.

[2]Quadratic time relationship.

*, ***Significant at $P < 0.05$ and 0.001, respectively.

TABLE 27

ANALYSIS OF VARIANCE OF CHLORIDE ION AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE

Source of Variation	d.f.	Mean Squares					
		0 Vs 1 Ampere			0 Vs 2 Amperes		
		13H	16H	22H	13H	16H	22H
Total	17						
Electricity (E)	1	33843	858355	829557*	3657520*	1752816*	4613911**
Error (a)	4	142530	120539	75859	248160	517019	107436
Position (P)	2	28327	429934	842398	2323624***	1578059**	4658382***
P x E	2	41198	704634	718828	3512790***	1615146**	4380251***
Error (b)	8	36609	163623	406147	24911	130709	44173

d.f. = Degrees of freedom

H = Time of Curing (hours).

*, **,***Significant at P<0.05, 0.01, and 0.001, respectively.

TABLE 28

ANALYSIS OF VARIANCE OF CHLORIDE ION AS AFFECTED BY TIME (HOURS) OF CURING

Source of Variation	d.f.	Mean Squares			
		1 Ampere		2 Amperes	
		Control	Treated	Control	Treated
Total	26				
Time[1]	1	1101654***	2824451*	1584	119445
Time[2]	1	16254	193350	131596*	154910
Error	24	27922	490307	27397	1690449

d.f. = Degrees of freedom

[1]Linear time relationship.

[2]Quadratic time relationship.

*Significant at $P < 0.05$.

TABLE 29

ANALYSIS OF VARIANCE OF SODIUM ION AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE

Source of Variation	d.f.	Mean Squares					
		0 Vs 1 Ampere			0 Vs 2 Amperes		
		13H	16H	22H	13H	16H	22H
Total	17						
Electricity (E)	1	14232	360983	348872*	1538178*	737151	1940391*
Error (a)	4	599444	50693	31903	104364	217436	45183
Position (P)	2	11913	306975	375300	977205***	663656**	1959093***
P x E	2	17326	296335	302326	1477733***	679463**	1842125***
Error (b)	8	15396	68812	170806	10477	54970	18577

d.f. = Degrees of freedom

H = Time of Curing (hours).

*, **,*** Significant at $P<0.05$, 0.01, and 0.001, respectively.

TABLE 30

ANALYSIS OF VARIANCE OF SODIUM ION AS AFFECTED BY TIME (HOURS) OF CURING

Source of Variation	d.f.	Mean Squares			
		1 Ampere		2 Amperes	
		Control	Treated	Control	Treated
Total	26				
Time[1]	1	463303***	1187829*	666	50233
Time[2]	1	6835	81313	55343*	65147
Error	24	11743	206200	230435	710922

d.f. = Degrees of freedom

[1]Linear time relationship.

[2]Quadratic time relationship.

*, ***Significant at $P < 0.05$ and 0.001, respectively.

TABLE 31

ANALYSIS OF VARIANCE OF DENATURED NITROSOMYOGLOBIN AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE

Source of Variation	d.f.	Mean Squares					
		0 Vs 1 Ampere			0 Vs 2 Amperes		
		13H	16H	22H	13H	16H	22H
Total	17						
Electricity (E)	1	1.13	17.01	55.97***	3.54	3.72	0.38
Error (a)	4	55.29	87.20	13.99	43.94	45.45	3.21
Position (P)	2	1.99	31.49	1.40	1.36	8.39	0.89
E x P	2	0.40	62.45	1.47	0.57	2.26	0.59
Error (b)	8	2.39	27.00	1.18	2.41	3.21	2.49

d.f. = Degrees of freedom

H = Time of Curing (hours).

*Significant at $P<0.05$.

TABLE 32

ANALYSIS OF VARIANCE OF DENATURED NITROSOMYOGLOBIN AS AFFECTED BY TIME (HOURS) OF CURING

Source of Variation	d.f.	Mean Squares			
		1 Ampere		2 Amperes	
		Control	Treated	Control	Treated
Total	26				
Time[1]	1	148.04*	34.00	21.32*	21.04
Time[2]	1	175.73	149.05**	76.04	4.86
Error	24	31.29	13.72	14.21	9.37

d.f. = Degrees of freedom

[1]Linear time relationship.

[2]Quadratic time relationship.

**Significant at $P < 0.01$.

TABLE 33

ANALYSIS OF VARIANCE OF TOTAL PIGMENT AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE

Source of Variation	d.f.	Mean Squares					
		0 Vs 1 Ampere			0 Vs 2 Amperes		
		13H	16H	22H	13H	16H	22H
Total	17						
Electricity (E)	1	28.78	226.84	7.00	0.12	45.98	71.60
Error (a)	4	91.44	223.50	12.11	238.34	186.12	95.77
Position (P)	2	51.42	1.01	40.79	3.84	32.94	5.43
P x E	2	1.73	5.90	22.79	34.87	0.02	105.00
Error (b)	8	12.78	6.54	31.74	37.50	101.99	77.99

d.f. = Degrees of freedom

H = Time of Curing (hours).

***Significant at P<0.001.

TABLE 34

ANALYSIS OF VARIANCE OF TOTAL PIGMENT AS AFFECTED BY TIME (HOURS) OF CURING

Source of Variation	d.f.	Mean Squares			
		1 Ampere		2 Amperes	
		Control	Treated	Control	Treated
Total	26				
Time[1]	1	6.57	16.60	305.71	811.86*
Time[2]	1	92.71	159.18	128.13	0.47
Error	24	38.79	43.04	95.71	359.65

d.f. = Degrees of freedom

[1]Linear time relationship.

[2]Quadratic time relationship.

TABLE 35

ANALYSIS OF VARIANCE OF CURED COLOR AREA AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE

Source of Variation	d.f.	Mean Squares					
		0 Vs 1 Ampere			0 Vs 2 Amperes		
		13H	16H	22H	13H	16H	22H
Total	17						
Electricity (E)	1	19.06	86.90	0.10	127.84	1831.94	0.80
Error (a)	4	122.62	93.47	8.96	126.32	240.82	0.25
Position (P)	2	96.38	253.35*	0.62	176.62	293.71	0.03
P x E	2	20.76	25.41	2.45	22.88	297.83	0.03
Error (b)	8	46.21	32.89	1.53	48.23	445.31	0.18

d.f. = Degrees of freedom

H = Time of Curing (hours).

*Significant at $P<0.05$.

TABLE 36

ANALYSIS OF VARIANCE OF CURED COLOR AREA AS AFFECTED BY TIME (HOURS) OF CURING

Source of Variation	d.f.	Mean Squares			
		1 Ampere		2 Amperes	
		Control	Treated	Control	Treated
Total	26				
Time[1]	1	443.63**	537.10**	1100.80	19.51
Time[2]	1	35.10	61.29	6436.86**	21.75
Error	24	46.80	152.49	540.71	21.70

d.f. = Degrees of freedom

[1]Linear time relationship.

[2]Quadratic time relationship.

**Significant at $P < 0.01$.

TABLE 37

ANALYSIS OF VARIANCE OF CURED COLOR INTENSITY (L-VALUE) AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE

Source of Variation	d.f.	Mean Squares					
		0 Vs 1 Ampere			0 Vs 2 Amperes		
		13H	16H	22H	13H	16H	22H
Total	17						
Electricity (E)	1	13.78	58.46	309.26	0.89	7.95	15.14
Error (a)	4	3.90	4.41	369.61	395.22	15.74	125.47
Position (P)	2	20.52	70.17	7.88	0.33	0.17	1.75
P x E	2	12.76	21.95	1.48	2.12	3.01	110.05
Error (b)	8	4.05	20.77	3.50	10.24	0.97	88.67

d.f. = Degrees of freedom

H = Time of Curing (hours).

**Significant at P<0.01.

TABLE 38

ANALYSIS OF VARIANCE OF CURED COLOR INTENSITY (L-VALUE) AS AFFECTED BY TIME (HOURS) OF CURING

Source of Variation	d.f.	Mean Squares			
		1 Ampere		2 Amperes	
		Control	Treated	Control	Treated
Total	26				
Time[1]	1	17.65	800.79	2298.37***	1891.92***
Time[2]	1	0.16	166.82	146.07	87.17
Error	24	15.00	68.66	70.37	60.64

d.f. = Degrees of freedom

[1]Linear time relationship.

[2]Quadratic time relationship.

**, ***Significant at $P < 0.01$ and 0.001, respectively.

TABLE 39

ANALYSIS OF VARIANCE OF MOISTURE CONTENT AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE

Source of Variation	d.f.	Mean Squares					
		0 Vs 1 Ampere			0 Vs 2 Amperes		
		13H	16H	22H	13H	16H	22H
Total	17						
Electricity (E)	1	5.17	10.89	5.66	1.65	2.80*	9.21*
Error (a)	4	2.59	6.20	17.07	1.81	13.98	9.54
Position (P)	2	0.45	9.02	1.79	2.15	0.79	2.44
P x E	2	0.71	2.57	0.98	0.93	0.27	0.12
Error (b)	8	1.00	0.93	2.19	1.40	0.31	1.17

d.f. = Degrees of freedom

H = Time of Curing (hours).

*Significant at $P<0.05$.

TABLE 40

ANALYSIS OF VARIANCE OF MOISTURE CONTENT AS AFFECTED BY TIME (HOURS) OF CURING

Source of Variation	d.f.	Mean Squares			
		1 Ampere		2 Amperes	
		Control	Treated	Control	Treated
Total	26				
Time[1]	1	2.83	3.21	0.28	21.26**
Time[2]	1	22.31*	34.18**	0.35	1.10
Error	24	3.09	3.89	3.73	2.03

d.f. = Degrees of freedom

[1]Linear time relationship.

[2]Quadratic time relationship.

*, **Significant at $P < 0.05$ and 0.01, respectively.

TABLE 41

ANALYSIS OF VARIANCE OF JUICINESS (PRESSED FLUID RATIO) AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE

Source of Variation	d.f.	Mean Squares					
		0 Vs 1 Ampere			0 Vs 2 Amperes		
		13H	16H	22H	13H	16H	22H
Total	17						
Electricity (E)	1	0.05	0.21	1.29	0.43	0.72	2.63
Error (a)	4	2.26	1.09	2.90	0.12	2.25	1.75
Position (P)	2	0.51	0.58	0.68	0.01	8.58	1.38
P x E	2	0.42	0.61	1.00	0.18	1.44	0.37
Error (b)	8	0.35	0.56	0.68	0.21	4.38	1.06

d.f. = Degrees of freedom

H = Time of Curing (hours).

TABLE 42

ANALYSIS OF VARIANCE OF JUICINESS (PRESSED FLUID RATIO) AS AFFECTED BY TIME (HOURS) OF CURING

Source of Variation	d.f.	Mean Squares			
		1 Ampere		2 Amperes	
		Control	Treated	Control	Treated
Total	26				
Time[1]	1	1.31	5.24*	24.49***	12.37*
Time[2]	1	0.006	1.42	0.74	10.08
Error	24	0.90	0.91	0.49	7.85

d.f. = Degrees of freedom

[1]Linear time relationship.

[2]Quadratic time relationship.

*, ***Significant at $P < 0.05$ and 0.001, respectively.

TABLE 43

ANALYSIS OF VARIANCE OF TENDERNESS (WARNER-BRATZLER SHEAR VALUE) AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE

Source of Variation	d.f.	Mean Squares					
		0 Vs 1 Ampere			0 Vs 2 Amperes		
		13H	16H	22H	13H	16H	22H
Total	17						
Electricity (E)	1	4.21	2.40	0.57	5.74	10.29	0.01
Error (a)	4	40.62	11.93	18.85	18.07	66.53	11.42
Position (P)	2	34.70	20.73	9.33	4.89	90.43	21.31
P x E	2	13.48	5.95	5.63	14.45	25.60	0.21
Error (b)	8	11.94	7.96	5.00	6.81	33.88	5.62

d.f. = Degrees of freedom

H = Time of Curing (hours).

TABLE 44

ANALYSIS OF VARIANCE OF TENDERNESS
(WARNER-BRATZLER SHEAR VALUE)
AS AFFECTED BY TIME
(HOURS) OF CURING

Source of Variation	d.f.	Mean Squares			
		2 Amperes		1 Ampere	
		Control	Treated	Control	Treated
Total	26				
Time[1]	1	221.08	261.67	46.817	17.05
Time[2]	1	92.09***	93.60*	85.79	55.68
Error	24	6.67	21.01	91.78	41.76

d.f. = Degrees of freedom

[1]Linear time relationship.

[2]Quadratic time relationship.

*, ***Significant at $P < 0.05$ and 0.001, respectively.

TABLE 45

ANALYSIS OF VARIANCE OF COOKED MEAT pH AS AFFECTED BY ELECTRICAL CURRENT LEVEL, CURING TIME AND POSITION IN MUSCLE

Source of Variation	d.f.	Mean Squares					
		0 Vs 1 Ampere			0 Vs 2 Amperes		
		13H	16H	22H	13H	16H	22H
Total	17						
Electricity (E)	1	0.006	0.020	0.009	0.040	0.003	0.035
Error (a)	4	0.176	0.050	0.132	0.007	0.298	0.038
Position (P)	2	0.007	0.222	0.016	0.007	0.038	0.275
P x E	2	0.027	0.018	0.003	0.007	0.003	0.004
Error (b)	8	0.014	0.020	0.62	0.006	0.025	0.153

d.f. = Degrees of freedom

H = Time of Curing (hours).

*Significant at $P<0.05$.

TABLE 46

ANALYSIS OF VARIANCE OF COOKED MEAT pH AS AFFECTED BY TIME (HOURS) OF CURING

Source of Variation	d.f.	Mean Squares			
		1 Ampere		2 Amperes	
		Control	Treated	Control	Treated
Total	26				
Time[1]	1	1.98***	1.98	2.56	1.47***
Time[2]	1	1.77	0.24*	1.38***	1.43***
Error	24	0.06	0.03	0.07	0.08

d.f. = Degrees of freedom

[1]Linear time relationship.

[2]Quadratic time relationship.

*, ***Significant at $P < 0.05$ and 0.001, respectively.

VITA

A. M. Shamsul Alam

Candidate for the Degree of

Doctor of Philosophy

Thesis: EFFECT OF ELECTROCHEMICAL CURING TECHNOLOGY ON THE DIFFUSION OF CERTAIN CURING AGENTS AND PHYSICOCHEMICAL QUALITY CHARACTERISTICS OF CURED MEAT

Major Field: Food Science

Biographical:

Personal Data: Born in Rangpur, Bangladesh, 1 February, 1952, the eldest son of Abul Kashem Talukder and Sufia Khatoon. Married to Rejina Chowdhury, 14 July, 1978 and father of Tasneem Sarah.

Education: Graduated from Sonatala Model High School, Bogra, Bangladesh, in April, 1966. Received the Bachelor of Science degree in Agricultural Engineering from Bangladesh Agricultural University, Mymensingh, in December 1973. Received Post-graduate diploma in Food Technology from United Nations/International Food Technology Training Center, Mysore, India in July, 1976. Received Master of Science degree in Food Technology from University of Mysore in April 1978 and Master of Science degree in Food Biochemistry from State University of New York at Albany in December 1982. Fulfilled the requirements of the Doctor of Philosophy degree in Food Science, Oklahoma State University, Stillwater in May, 1988.

Professional Experience: Employed by Food Industries Corporation, Bangladesh as trainee (1973), Sugarcane Research Institute, Bangladesh as Assistant Sugar Chemist (1974), Institute of Food Preservation and Radiation Biology, Bangladesh as Senior Scientific Officer (1977-79), Bangladesh Agricultural University, Mymensingh as Examiner (1978), State University of New York at Albany, as Teaching Assistant, and Guest Lecturer (1979-81), Oklahoma State University, Stillwater as Research/Teaching Assistant (1981-84) and Carando Inc., Springfield, Massachusetts as Director of Quality Assurance (1984 - 85). Presently employed by Mosey's Inc. Bloomfield,

Connecticut, as Director of Quality Assurance and Research (1985-Present).

Professional Organizations: A member of the American Meat Science Association, Institute of Food Technologists, American Society of Quality Control and Association of Official Analytical Chemists.