Thermal Solutions

Meat Patty Temperature Variation

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Sheetal Desai

J.K. Evicks

Clara Rowden

Mohammed Siddiqui

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Mission Statement

Thermal Solutions is dedicated to satisfying client needs by developing innovative processing solutions.

Problem Introduction

Lopez Foods, Inc. is the largest Latino-owned producer of beef and pork products in the United States. The products processed in its Oklahoma City plant supply fast food and grocery retailers. During a final stage of the product processing, beef and pork products are cooked in custom-designed infrared (IR) ovens. No other version of these ovens exists in the industry.

Lopez Foods would like to increase the quality of their cooked meat products and reduce product loss. To help Lopez Foods attain this goal, Thermal Solutions is investigating factors that may be the cause of large temperature variations in the cooked meat patties. To monitor product quality, samples are taken from each patty across the oven belt every 30 minutes. Data from these cooked meat patties show that the internal temperatures of the patties range from 160°F to 190°F. This variation causes considerable safety, quality, and efficiency issues.

Statement of Work

Several factors may affect the temperature of the cooked product. To proceed in measuring the effect of various factors on the product temperature, an accurate method of data collection for the product temperatures must be ensured first. If the measured data is not accurate, the effect of the other parameters is impossible to determine.

As the first step towards eliminating the temperature variation, Thermal Solutions will analyze the current temperature measurement method to determine its reliability. If necessary, Thermal Solutions will investigate any deficiencies and recommend necessary changes.

Literature Review

The following is a review of literature to find the root cause of the temperature variation. This review of process control, infrared ovens, temperature measuring devices, and safety and quality in cooked meat patties is provided to give insight to the problem.

Process Control

Any manufacturing process can improve. Plant personnel improve these processes by modifying the input and output of the system. One way to continually improve is to continually evaluate the process. When plant personnel find problems, they sometimes use a method called the DMAIC problem solving method. Bowser (2005) indicates DMAIC consists of Defining the problem, Measuring parameters, Analyzing data, Improving the problem, and Controlling the improvements. The method is easy to follow and can be iterated if results are not satisfactory.

Bowser (2005) states that cause and effect diagrams are visual aids that identify all of the possible factors influencing a particular outcome. Bowser also states that this diagram organizes factors into related groups and aids in the brainstorming process. It is also called a fishbone diagram because of its shape—a fishbone. It has a central spine with “bones” extending laterally from the spine. The “bones” or groups extending from the spine are generally large groupings like environment, equipment, personnel, etc. From these larger groupings, more specific factors branch out to describe the large groupings. Cause and effect diagrams can be a very useful tool in problem solving.

Control limits are boundaries that represent how well the process is controlled (NIST, 2005). If the data falls within the control limits set for the process, then it is in control, and vice versa. Based on a normal distribution, these limits are some multiple of standard deviations from the mean of the data. The NIST states that this multiple of standard deviations is usually three in the United States. If some of the data is outside of the control limits, corrective action such as DMAIC should be taken.

Correlations tell the relationships between two variables. Frahme (2004) says this is usually done via correlation charts commonly known as scatter plots. If measuring more than one variable, statistical software packages can offer analyses that might not have been seen before. Frahme says that even though correlations show relationships, they cannot prove cause and effect since two correlated variables may have the same root cause. Frahme concludes that correlations should merely be a guide to future research to narrow the search for the source of the problem.

Infrared Ovens

Infrared ovens are becoming popular in industries that heat biological materials because of their ability to rapidly raise product temperature. These ovens operate at the most efficient range of radiation for heat transfer—the infrared spectrum.

The infrared spectrum includes all wavelengths between 0.75 – 1000 microns and is categorized into three parts:

1. Short-wave or near IR: 0.72 – 2 microns (3870 to 1180 C)
2. Medium-wave or middle IR: 2 – 4 microns (1180 to 450 C)
3. Long-wave or far IR: 4 – 1000 microns (< 450 C)

Lopez ovens most likely operate under far IR, the traditional method for heating biological materials (Fasina, 2003). To prevent charring of the biological material, IR oven temperatures stay within the 650-1200 °C range. IR also causes the surface of beef patties to lose moisture and fat. This loss results in the formation of a crust layer. However, according to Carnahan (2002) the lower cooking temperature of far IR results in less overall weight loss than hotter temperatures of shorter IR.

Temperature Measuring Devices

A variety of food thermometers are available in the marketplace. They are commonly categorized according to the type of sensor they use. Rund and Charlety (2005) identified three types of thermometers.

1. Thermocouple thermometers: measures temperature at the junction of the two wires located in the tip of the probe.
2. Thermistor thermometers: employs thermistors bounded in the tip of the probe typically with epoxy.
3. Bimetallic coil thermometers: contains a helix coil in the probe made out of two different metals that are bounded together. The metals have different rates of expansion

Lopez Foods uses a thermocouple thermometer (Atkins VersaTuff Model 386) to measure the internal patty temperature.

Food thermometers must be properly calibrated. Therefore, the accuracy of the reference thermistor is very important. The accuracy of the temperature read depends on the accuracy of the thermometer. Rund and Charlety (2005) state that a thermometer should be calibrated:

1. every day
2. after it is dropped
3. between uses of differing extreme temperatures

Meat Safety and Quality

Safety and quality are two main concerns of the food industry. Food poisoning, cross-contamination, and food-born illness demand the food processors to process meat at conditions set by recognized organizations like the Food and Drug Administration (FDA) and United States Department of Agriculture (USDA). The FDA states that the standard internal cooking temperature at which all the pathogens in a meat patty are destroyed is 160 ºF (FSIS, 2003).

The complexities involved in the heterogeneous mixture of meat and changing environment makes maintaining these standards a challenging issue. A single meat patty undergoes many physical and chemical changes during the cooking process. Non-uniform distribution of fat, protein, and water in the patty regulates the rates of heat and mass transfer. The most commonly observed physical change is likely the decrease in diameter and thickness due to drainage of fat and water. This change enhances the variation heat transfer throughout the cooking process (Singh, R.P., 2005).

Color, texture, or other visible signs are misleading factors to the doneness of a patty. Research done by USDA (2003) shows that one out of every four hamburgers turns brown before reaching the safe internal temperature (FSIS, 2003). If the patty reaches 160 ºF internally, the meat is safely cooked even if the meat is pink inside. The most appropriate technique to judge the doneness of a patty is to measure the internal temperature.

In a large scale cooking process, the time a patty stays in the oven must be controlled. If the belt speed is fast, a thin crust forms on the outer surface of the patty. This surface makes the patty stiff and the lack of moisture and fat slows heat transfer. The speed of the conveyor must correspond to the heat supplied and cooking time (Singh, R.P., 2005).

Customer Requirements

Lopez Foods stated that Thermal Solutions needs to find the main parameter(s) that can be managed to solve 75 – 80% of the temperature variability. Once that parameter is found, it must be controlled. Eliminating this variability will make the process much more predictable and the product more uniform.

Possible Factors

After visiting Lopez Foods, Thermal Solutions composed a list of possible factors that may cause the non-uniform heating of the meat patties. A cause and effect diagram is shown in Figure 1 to show how these factors are related.

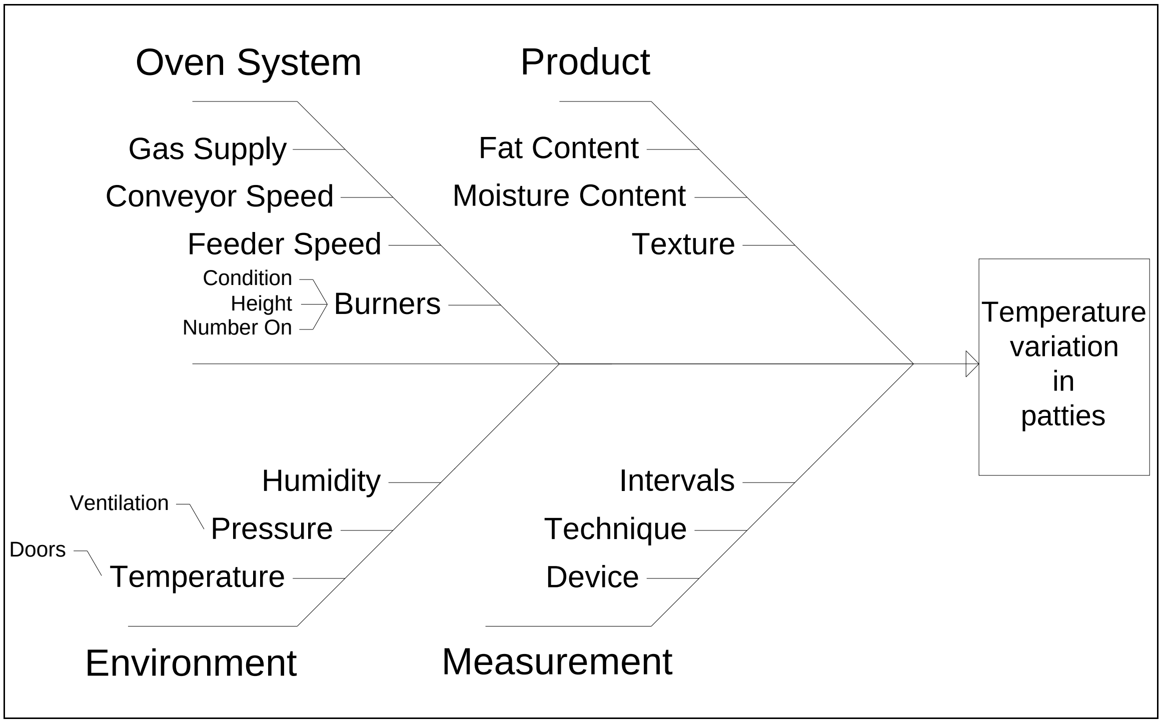

Figure 1. Cause and Effect Diagram

Environment

The oven room environment is the first parameter Thermal Solutions investigated. The oven room is located between the meat grinding room and the freezer room which are both at very low temperatures. The oven room ventilation system operates at a negative pressure; that is, more air is ventilated out of the room than forced in. This unbalanced air pressure leads to a rush of cooler air when the doors connecting the oven room and the cooler adjacent rooms are opened. These frequently opened double doors lead to heat loss and increased humidity in the oven room over a short period of time. Figure 2 shows the oven room layout. These continuous changes in temperature and humidity of the oven room may affect the cooking process.

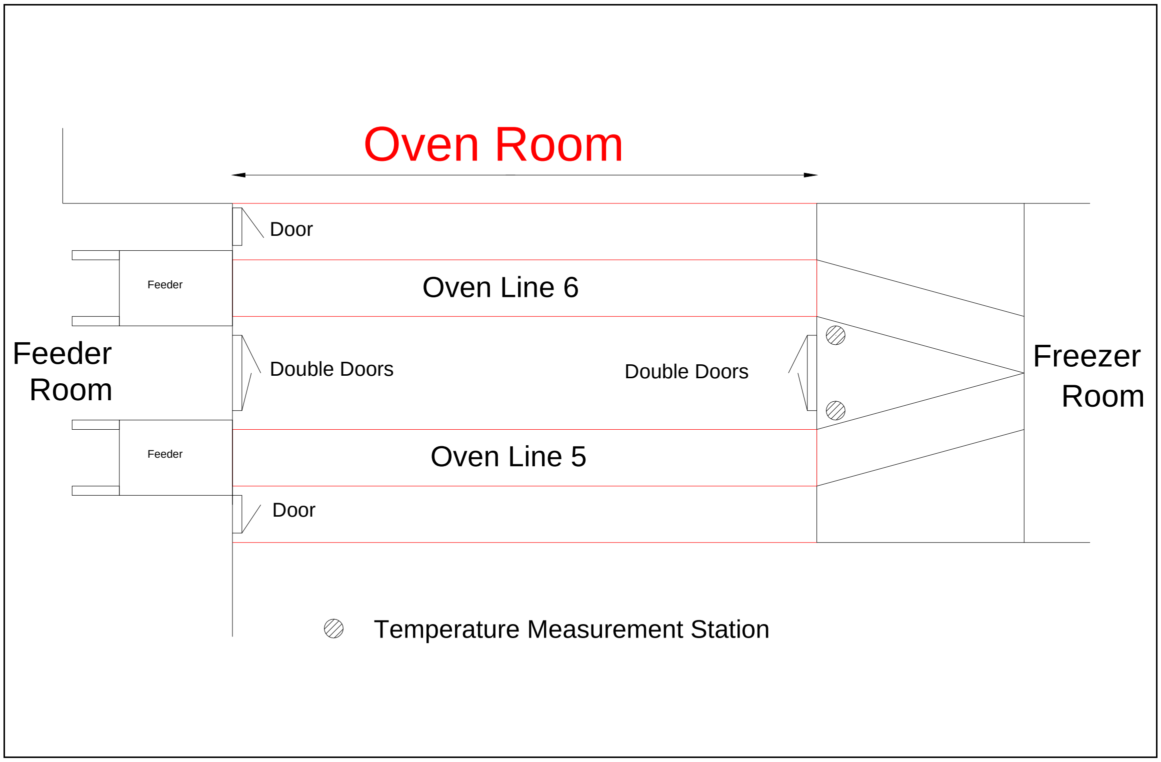

Figure 2. Oven Room Layout

Product

Irregularities in the meat patty composition may cause different meat patties to heat at different rates. Since the raw meat Lopez receives varies continually in composition, Lopez grinds varying amounts of fat and moisture with the meat ensure a uniform patty composition. Even after mixing, it is still difficult to fully control uniform composition of each meat patty.

Oven System

Lopez's infrared ovens are custom-designed. As seen in Figure 2, there are two oven lines in the fully-cooked oven room. The sides of the ovens near the center of the room are covered by a hanging control panel. The other sides are open to the environment.

Each of these oven lines consists of three sections; the first and second sections each have five burner bays and the third section has only two burner bays. Each burner bay is comprised of six burners. These burners are powered by natural gas and are typically approximately three inches above the conveyor belt.

The oven system is defined in Figure 2 to include the Formax machine in the feeder room and the oven itself. The patties are first formed by the Formax machine and are conveyed from the feeder room into the oven room. While in the oven, the patties travel down the three conveyors of the three different oven sections. During this process, the patties are flipped twice—once after the exiting the first oven section and again after exiting the second oven section. Finally, the patties exit the oven room and continue into the freezer room and into a blast freezer. The patty temperature is recorded in the freezer room.

Various components in this oven system can greatly influence the temperature of the meat patties. The oven components of concern are the gas supply, feeder speed, conveyor speed, burner height, and burner conditions.

The gas supply controls the amount of heat the oven supplies. Variations in pressure or energy value of the gas could cause a direct variation in oven temperature. According to Oklahoma Natural Gas (ONG) representatives, these variations are dependent on the location of the gas outlet in the supply system. The heating values of the gas can change from 1,020 BTU/ft^3 to 1,120 BTU/ft^3 (change of 100 BTU/ft^3) within an hour at the far end of the supply line. However, daily variances of heat content normally may have a magnitude of 15-25 BTU/ft^3.

The Formax machine forms patties and drops them on the belt. The rate of this machine may cause temperature changes according to the meat load it deposits in the oven.

The conveyer belt speed also changes the rate at which the patties go through the oven. This speed works in conjunction with the Formax speed to determine patty spacing, overall oven temperature, and cooking time. As stated earlier, three separate conveyors comprise the oven system. Each of these conveyors operates at a different speed. These speeds are adjusted throughout the day as the floor operator determines fit.

The height of these burner bays is usually three inches above the conveyors. Their height, however, may be changed to increase the patty cooking rate or to alter the patties' puffiness and weight loss. Usually only the burner height above the second conveyor belt is adjusted to correct these characteristics.

The burners' individual performance and condition relates to the performance of the entire oven. The conditions of each oven burner vary dramatically from good condition to blacked out even though Lopez technicians work each day to repair and replace these burners. A few even catch fire while in operation and are left to extinguish themselves over time. This varying number of burners in good operating condition may affect the amount of the oven's heat output and therefore the cooking process of the patties.

Operators vary feeder speed, conveyor speed, burner height, and the number of burners operating to maintain the correct temperature and weight for the respective product. For example, if patties are over the specified weight, then the operator may decrease the conveyor speed or lower the burner height to meet the specification. These parameters are all changed in varying extents on different days at different times. While these variations are intended to make the patty temperatures and weights more uniform, they are made according to an individual's experience and not with the proper knowledge of the magnitude of their effects.

Temperature Measurement Method

Temperature measurement technique itself may be a significant factor. The USDA states that the internal temperature of the meat patty must stay at a certain temperature for a specified length of time. The USDA gives several different combinations of temperature/time relationships to choose from, but Lopez uses 157°F for 10 seconds. This temperature reading must be taken at the geometric center of the patty because it normally is the point that takes the longest to reach the critical temperature. At Lopez, however, this cool point may not be in the center of the patty due to the flipping of the patties and the additional cooking of the third oven section.

To determine the temperature of the center of the patty, employees at Lopez Foods insert the thermocouple probe into the side of the patty for 10 seconds (Figure 3). The accuracy of this technique in measuring the temperature of the patty's geometric center is questionable; there is no indicator for knowing how far to insert the probe horizontally or where the height of the probe tip is within the patty. When members of Thermal Solutions attempted this technique, the probe sometimes stabbed through the bottom or top of the patty unintentionally.

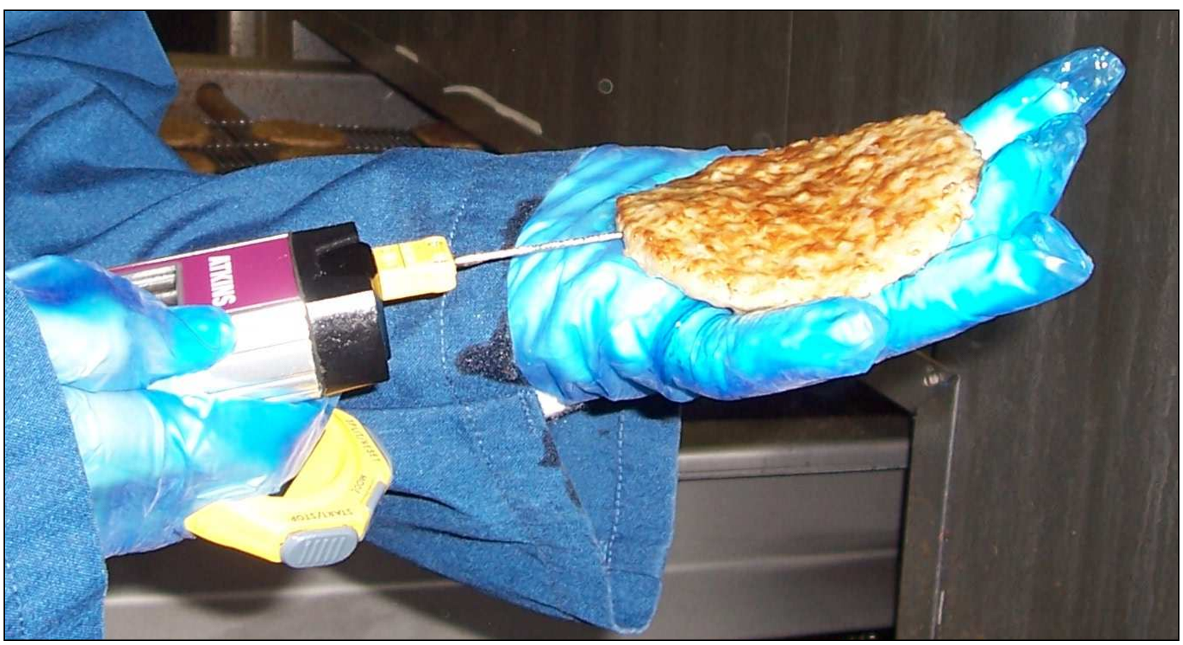

Figure 3. Traditional Temperature Measurement Technique

Factor Determination and Testing Methods

Thermal Solutions obtained patty temperature measurements of the patties cooked by the two ovens. This initial data, displayed in Figure 4, shows that average patty temperatures from both ovens vary at the same time. This trend indicates that the temperature variation of the ovens generally track each other. Therefore, the main factor appears to affect both ovens and other factors specific to each oven, such as burner condition, can be eliminated.

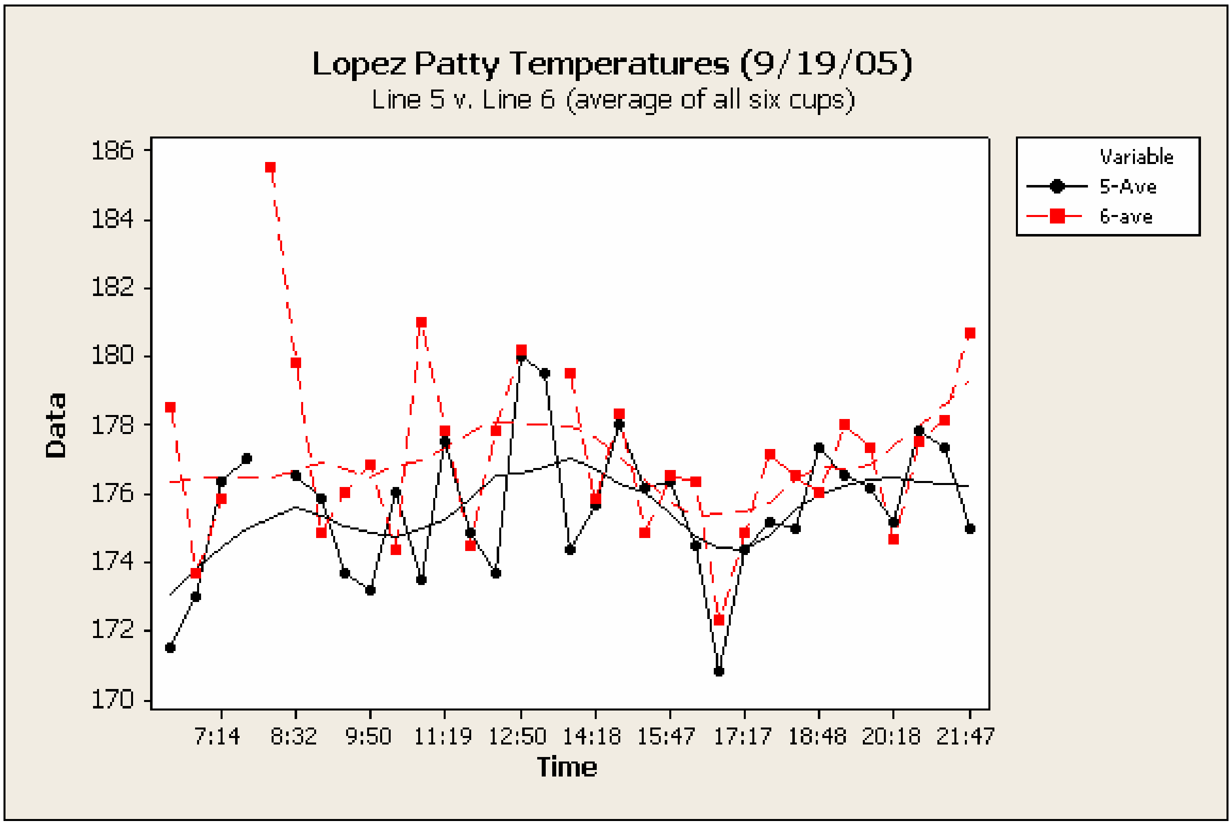

Figure 4. Oven Correlation

Thermal Solutions also gathered data on the product composition before selecting factors to test. This investigation showed that the composition of the product did not have a very high variability; the fat variation is only 2% and the added water content is only 3%. These figures do not warrant the variability seen in the temperature distribution, so variation in the product composition was eliminated.

From the remaining list of factors, Thermal Solutions chose to evaluate factors that were deemed to have the most impact and were possible to test. These chosen factors are temperature variation in the oven, environmental variation, and temperature measurement technique.

Oven Profile

Dr. Timothy Bowser, a technical consultant for Thermal Solutions, suggested a profile test to determine how temperature varies across the length and width of the oven. Figure 5 shows the first apparatus Thermal Solutions used to profile the oven.

Figure 5. First Data Logger Apparatus

A Pace Scientific XR440® data logger was placed inside an insulated enclosure in the apparatus in Figure 5 to prevent heat damage to the instrument. Four wires covered in PFTE tubing extended from the logger enclosure to four thermistors. These thermistors represent four channels across the conveyor belt.

This data logger design was only partially successful. The oven burners were much lower than expected and hindered testing of all three sections of the oven. Therefore, only the first section of the oven was profiled. This data appears in Figure 9.

Due to the problems encountered with the first profiling apparatus, Thermal Solutions redesigned a new model. By carrying the data logger outside the oven, the overall height of the apparatus was greatly reduced. A Fluke Hydra II data logger replaced the former logger to collect data over six channels of the oven instead of the previous four. Figure 6 shows the new oven profiler. With this new model, data was collected for all three sections of the oven. The data from these trials is presented in Figure 10. Drawings of both profilers may be seen in Appendix 6.

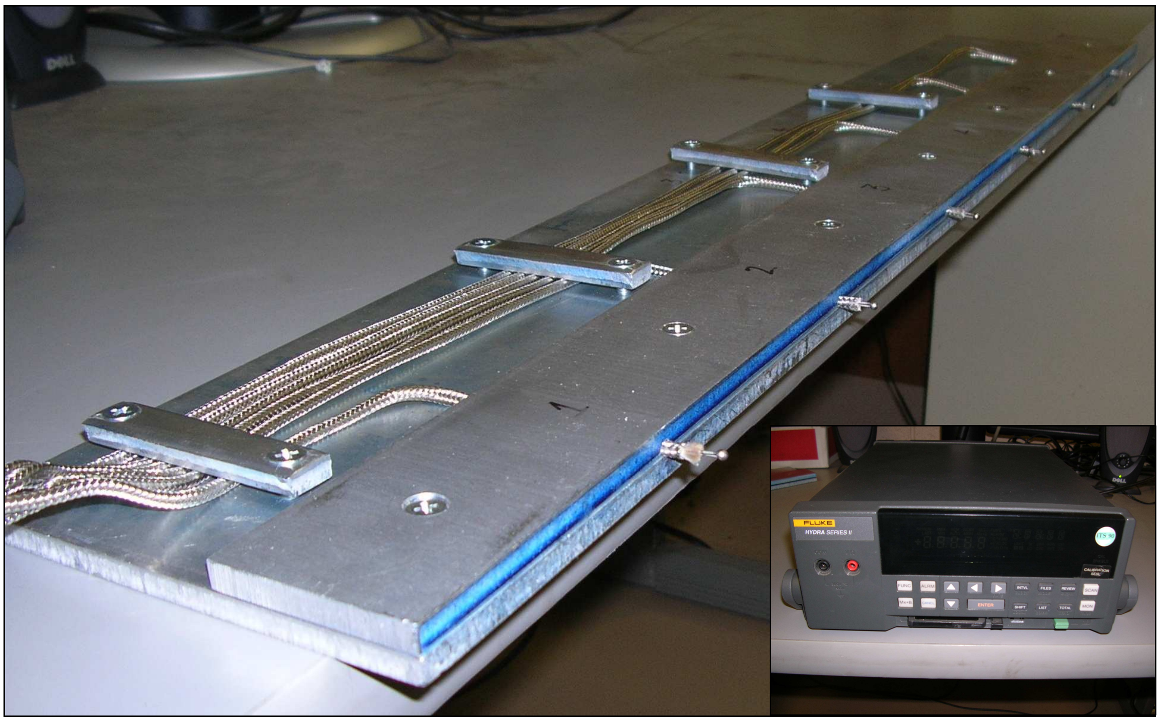

Figure 6. Second Oven Profile Apparatus, Inset: Fluke Hydra II Data Logger

Environmental Variation

Unlike other factors, the room environment is not measured regularly. Room environment varies due to the oven load and air flow in and out of the room. An Onset Hobo® U12-013 data logger recorded temperature and relative humidity every minute for a one week period. This test was designed to determine the effect of room environment on patty temperature. Figures 11 and 12 show room temperature data.

Temperature Measurement Comparison

To determine the accuracy of Lopez's temperature measurement technique, Thermal Solutions measured the temperature of patties with two different devices at the same time. The first device was the standard thermocouple probe that Lopez currently uses (Refer to Figure 3). The second device was a custom-made thermocouple probe designed by Dr. Timothy Bowser (Figure 7). This device ensures that the temperature is measured at the center of the patty by fixing the thermocouple height in the device.

Figure 8 shows a newer version of the disc probe. The additional side wall was added to help reduce heat loss of the patty while its temperature is being measured. During testing, however, it was determined that the first disc probe design was superior because it allows the user to place the patty on a flat surface and insert the probe from above. This method ensures the probe has sufficient penetration into the patty versus probe insertion from the bottom of the patty. Appendix 6 contains the drawings for both disc designs.

Figure 7. Disc Thermocouple Probe

Figure 8. Second Disc Thermocouple Probe

To ensure accurate testing, Thermal Solutions first tested the calibration of the two temperature devices. Thermal Solutions employed two different tests to compare the traditional method to the new disc method. During the first test, both thermocouple devices measured temperature after 10 seconds within the same patty. This process was completed for approximately 30 patties to find the difference in instantaneous measurements. Figure 15 shows the results of this test.

During the second test, Thermal Solutions measured the temperature decrease of patties every five seconds for a one minute period (see Figure 16). Again, like the previous test, both probes were inserted into the same patty at once. Data for three patties was obtained.

Design of Experiment (DOE)

Thermal Solutions has spent much time researching a method called Design of Experiment (DOE) to determine the amount of impact various factors have on the cooked patty temperature. The DOE uses statistical analysis over a series of experimental trials. In these trials, one factor is varied while all other factors are held constant. Many forms of DOEs exist, but the two-level factorial design, in which level one is the lowest value of a factor and level two is the highest value, fits this problem best. After learning the basics of DOE from Rajesh Krishnamurthy, a graduate Industrial Engineering student at

OSU, Thermal Solutions found that a DOE could identify the optimal operating settings for the continually varied oven parameters at Lopez. Appendix 5 contains more information on a DOE at Lopez.

The disadvantage to a DOE is the large number of experiment trials required for accurate results. In a two-level factorial DOE, the number of trials (N) is found by the following equation with *f* being the number of factors: $N = 2^f$. This means if there are 5 factors, then 32 trials are required to get accurate results. Since Lopez operates continuously, performing 32 experimental trials would require a vast amount of line time and hence be very costly.

Even if cost were not an issue, a DOE may not provide meaningful results for all products. Lopez manufactures three different sizes of product and several different mixes on the same fully-cooked line. If a DOE were performed, it would need to be performed for each product of each size.

The third obstacle is the inability to hold all factors constant while varying only one factor at its highest and lowest level. Holding factors, such as room temperature, constant and then varying it to its highest and lowest value is not feasible. There is also interaction between factors. Changing the speed of the first conveyor will require changing the feeder speed and the speed of the other conveyors.

For the aforementioned reasons, Thermal Solutions chose not to perform a DOE at Lopez Foods. A project of this magnitude would likely necessitate a full-time engineer at Lopez.

Thermal Camera

A Flir ThermaCAM® (Model E25) was used to characterize the temperature profile of the patty cross section using thermal imagery. Thermal Solutions conducted two tests to find this cross sectional temperature profile. The first test was conducted to at OSU's Food and Agricultural Products Center (FAPC). During this testing, Thermal Solutions ensured proper calibration of the thermal camera and obtained preliminary data of temperature profiles of cooked meat. The second test was held at Lopez Foods with the actual sausage patties exiting the oven. The thermal images were taken by cutting the patties in half and taking a picture of the cross section as quickly as possible before significant heat loss occurred.

Factor Test Results and Analysis

Oven Profile

The data acquired from the first oven profile provided meager results (Figure 9). Since the data logger recorded the temperature continuously, even while outside of the oven, the data from the different thermistors appears as hot peaks from being inside the oven and cool dips from being outside the oven. The first three set of peaks represents three passes down the first section of the oven with the doors open, while the second set represents three passes with the doors closed. This profile only allowed four channels, with channel one being closest to the center of the room and channel four being closest to the side of the oven open to the environment.

Figure 9 shows channel one is consistently lowest in temperature, regardless of whether the doors are open or closed. Channel two is consistently highest in temperature with the doors open, but lower than three and four with the doors closed. Channel three and four (closest to wall) were very close to each other in temperature in both runs with three being slightly higher.

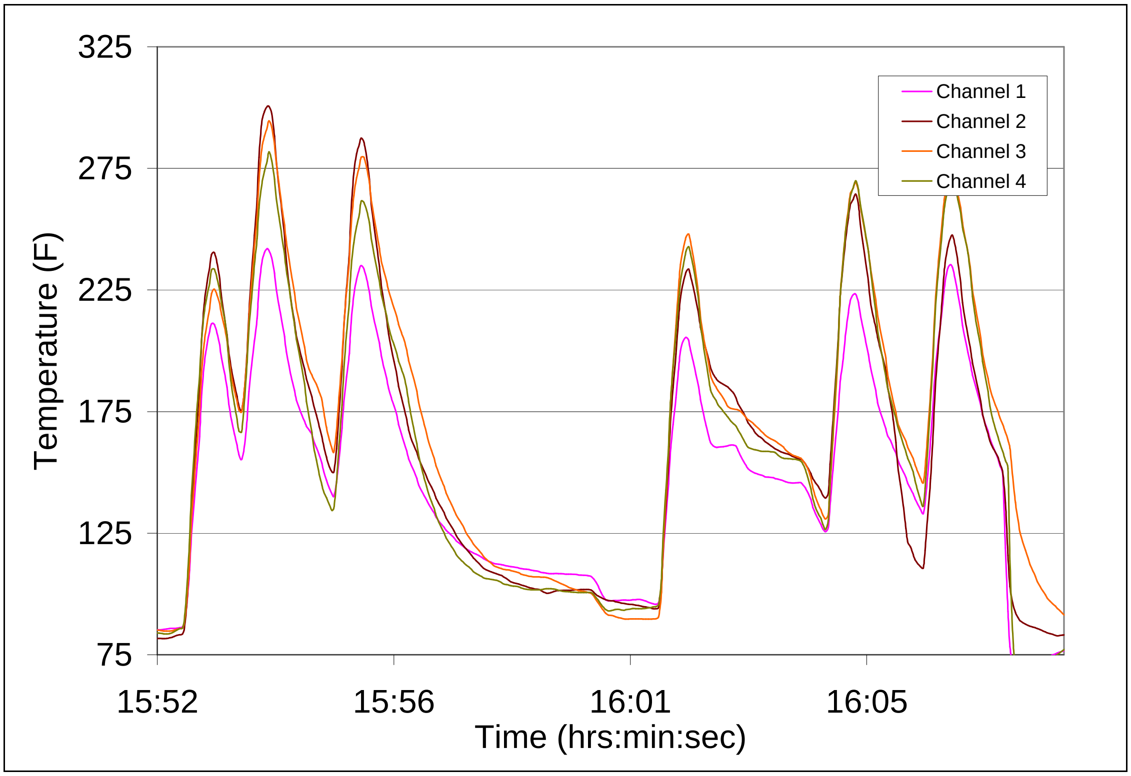

Figure 9. First Oven Temperature Profile

The most significant feature of the data in Figure 9 is the temperature difference between the channels within each peak. These differences range from 30-50 °F. This shows that there may be a significant temperature variation across the width of the oven. Appendix 2A contains more charts from this oven profile.

The second oven profiling apparatus provided more information due to more channels across the line and that all three oven sections were profiled. The six channels represented each of six patties that sit across the conveyor belts. For the second oven profiler, the channel numbers were actually numbered in the reverse direction of the first. Therefore, channel six represents the patty closest to the center of the room and channel one represents the patty sitting on the oven side open to the environment.

As seen in Figure 10, all six channels across the belt increase as they advance down each of the three conveyor belts. Since the data logger was promptly started at the beginning of each conveyor and stopped as it finished each conveyor, one can see how the temperature varies with conveyor length. Using the new oven profiler, three profiles were conducted with the doors closed and two profiles were conducted with the feeder room doors open. Additional profiles could not be conducted due to the cost of stopping patty production for profiling.

The oven profile by the new profiler shown in Figure 10 reinforces the 30°F temperature variation across the conveyor belt at any given time. All three conveyors show an increase of temperature over time, but in the first section, the temperature actually peaks and decreases before the end of the conveyor. The reason for this phenomenon is not known at this time.

Analysis of the five new oven profiles also showed that channel five consistently averaged the highest temperature for each conveyor belt. Also apparent is that the variation between the maximum and minimum temperature for each channel on each belt was largest for channel one and reduced uniformly across the belt towards channel six. This may be due to the fact that channel six is shielded from cool air rushes by the control panel and that channel one is exposed to the open air. Appendix 2B contains more charts from this oven profile.

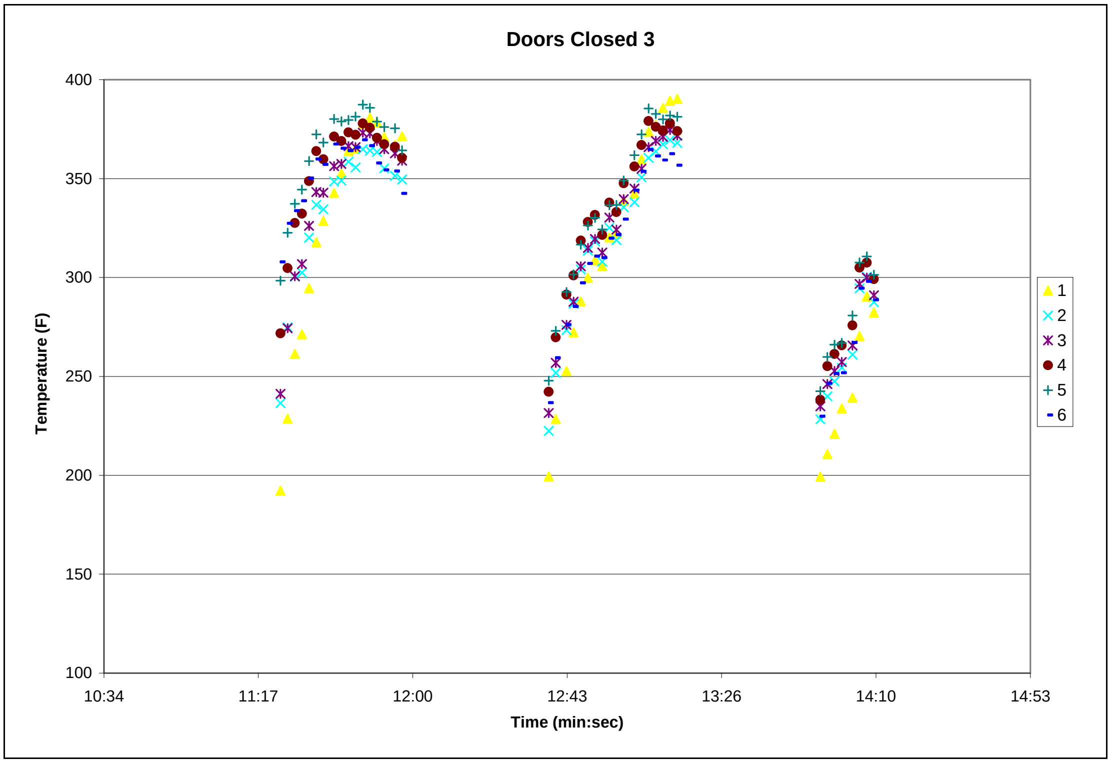

Figure 10. Oven Temperature Profile with New Profiling Apparatus

Environmental Variation

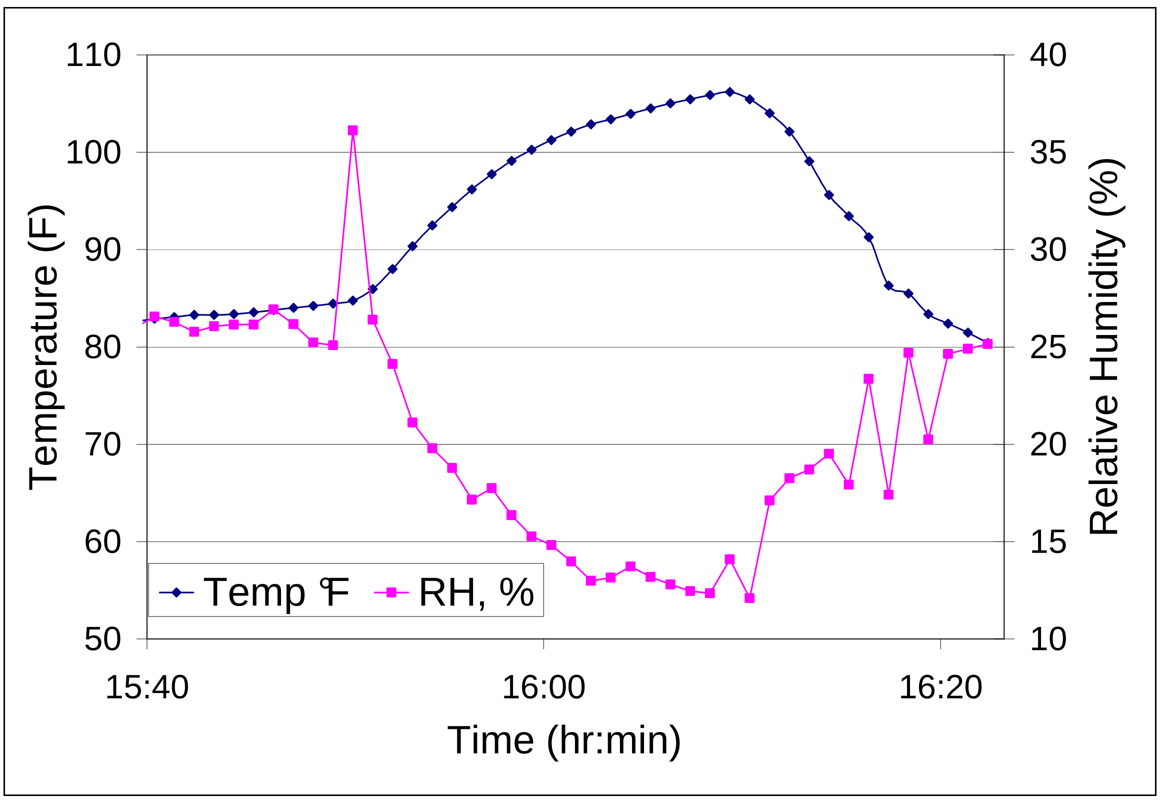

Figure 11. Door Effects on the Environment

Thermal Solutions

As stated earlier, room environment varies due to the oven load and air flow in and out of the room. For example, when the door is closed, the temperature may increase 20 degrees. Figure 11 shows the temperature rise and relative humidity drop as the door is closed (at time 15:50).

Figure 12 compares the environmental room data to the corresponding patty temperature measurements. By analyzing this data, Thermal Solutions determined that overall environmental changes in temperature and relative humidity do not affect patty temperatures.

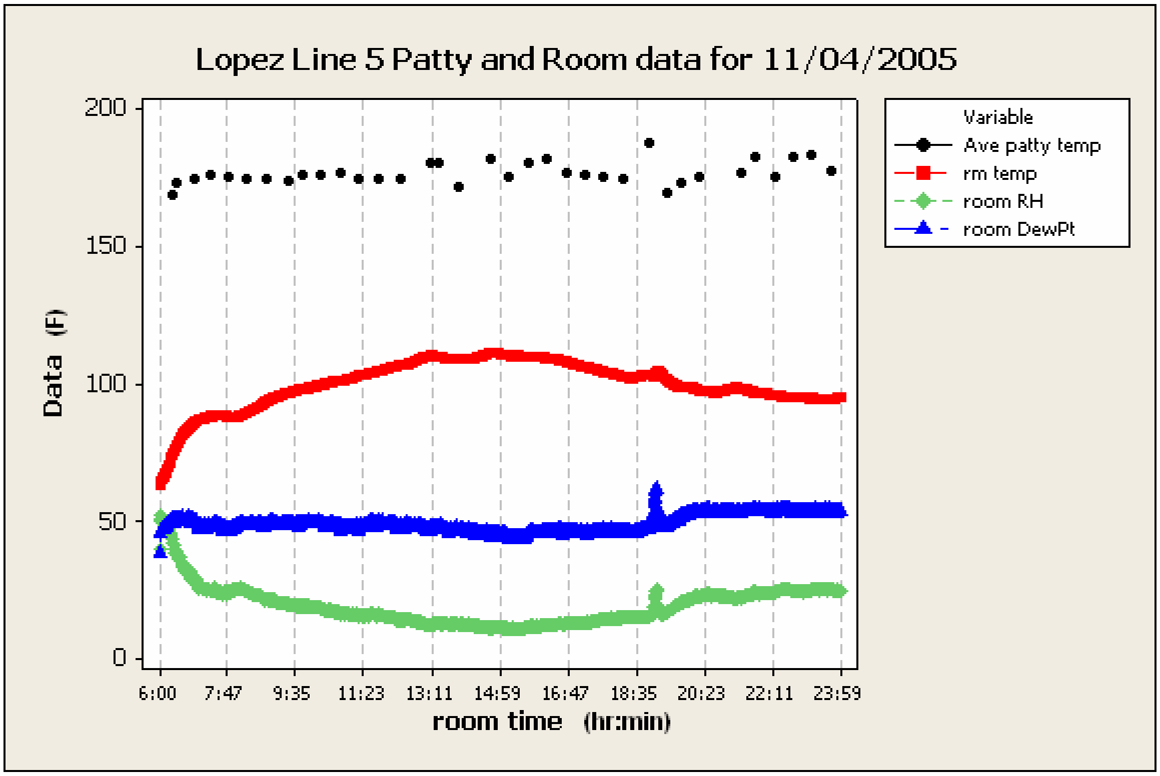

Figure 12. Patty Temperature vs. Room Environment

Thermal Camera

The subsequent figures show examples of thermal images taken with the Flir camera. More thermal images may be seen in Appendix 4.

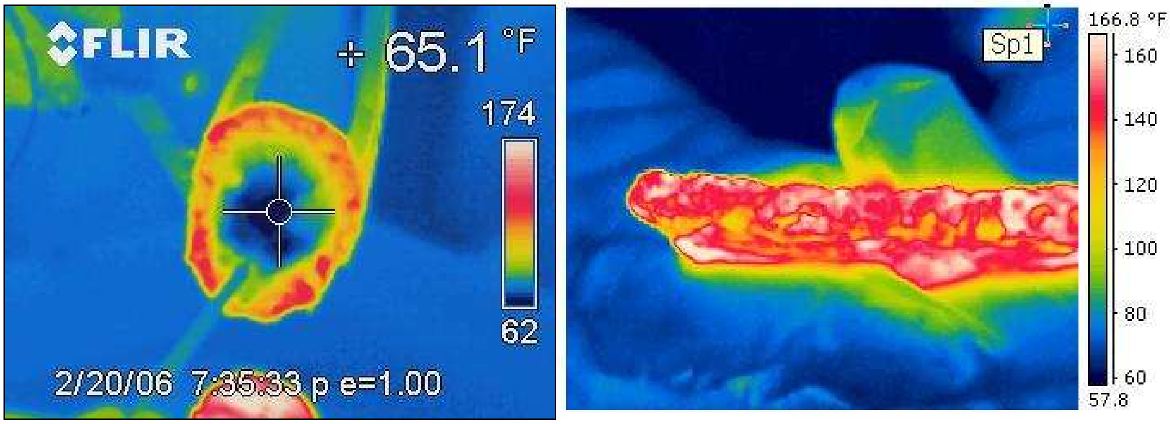

Figure 13. Thermal Images from Infrared Camera
(Left) Sausage chunk cooked at OSU's FAPC. (Right) Sausage patty at Lopez Foods (#245).

Figure 13 and 14 show the temperature inconsistencies of the sausage patties. The line profile in Figure 14 is a temperature profile of the white vertical line drawn through the center of the patty. This line profile shows that the patties have a nonuniform temperature profile. Analysis of 12 patty profiles revealed no trends; each profile consisted of random hot spots. This variability is likely due to the heterogeneous nature of the mixed meat.

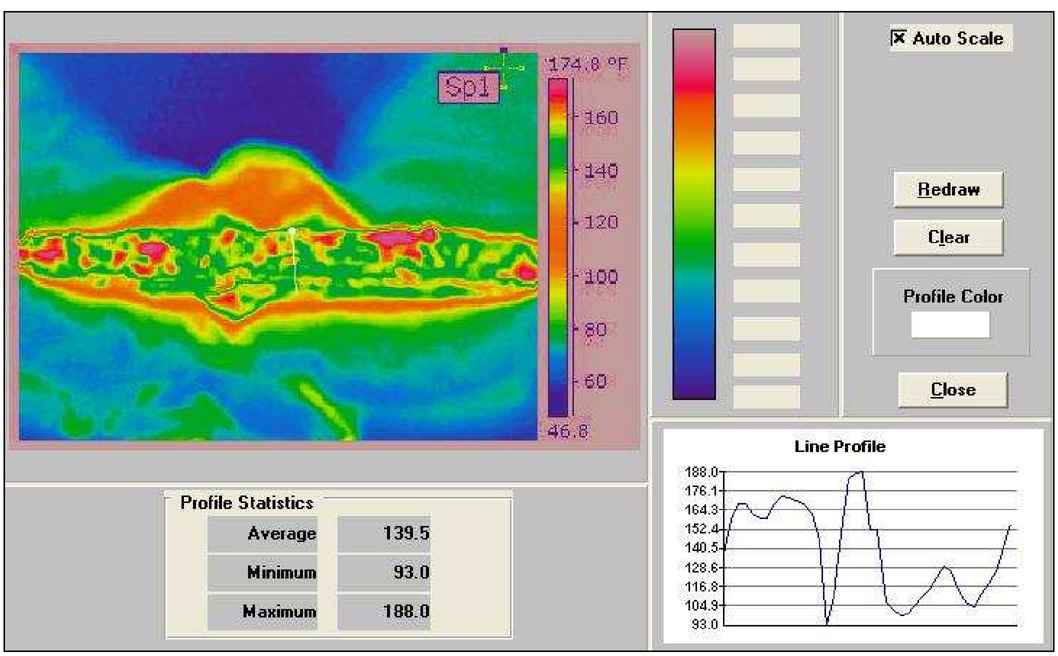

Figure 14. Thermal Camera Software Analysis

Measurement Technique Comparison

As stated earlier, Thermal Solutions compared the temperature measurement devices. Figure 15 shows that the data for the each of the measurement devices seems to be very similar. For example, when the temperature recorded on one device is higher than average, then the temperature recorded on the other device tends to be higher than average. However, the temperature difference in the two devices ranges from 2 °F to 12 °F. This data suggests that the disc-type probe is fairly constant in temperature measurement, while the traditional side probe varies in temperature.

The result of the transient temperature measurement comparison is shown in Figure 16 on the next page. Though this comparison used only three patties, this data suggests that the disk probe is more repeatable than the traditional side probe.

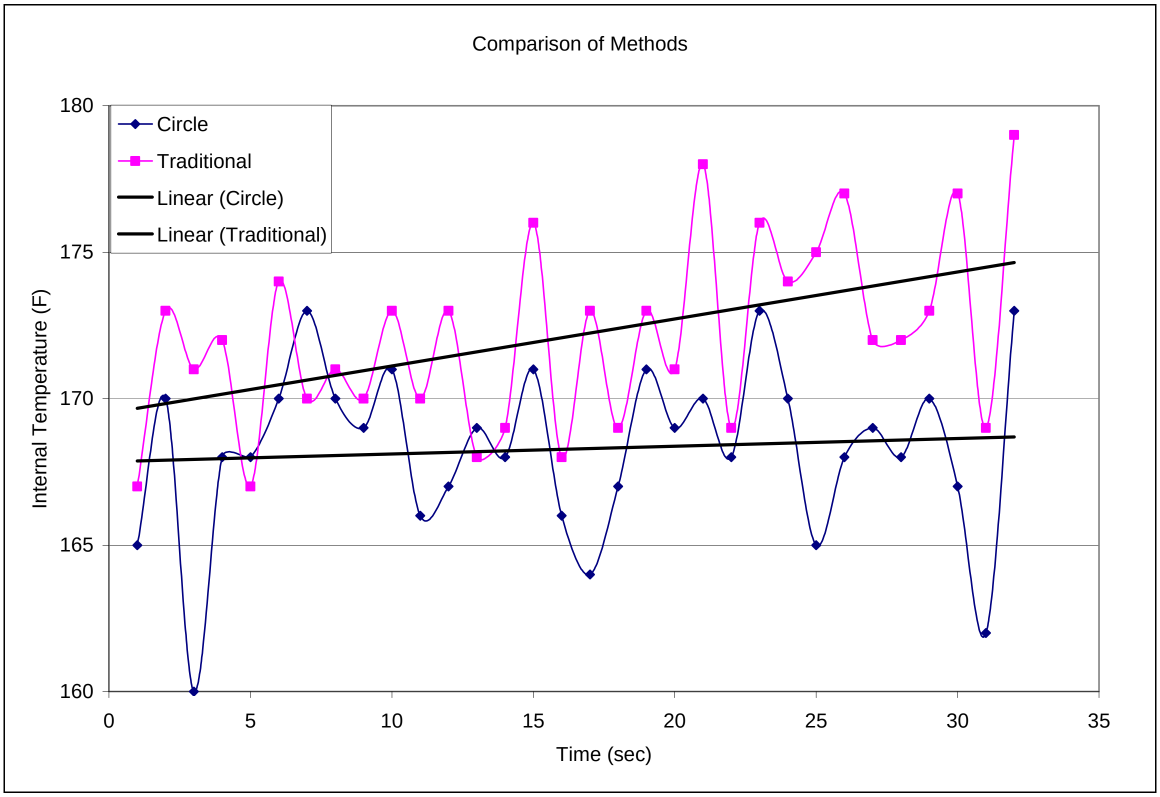

Figure 15. Temperature Measurement Comparison (instantaneous)

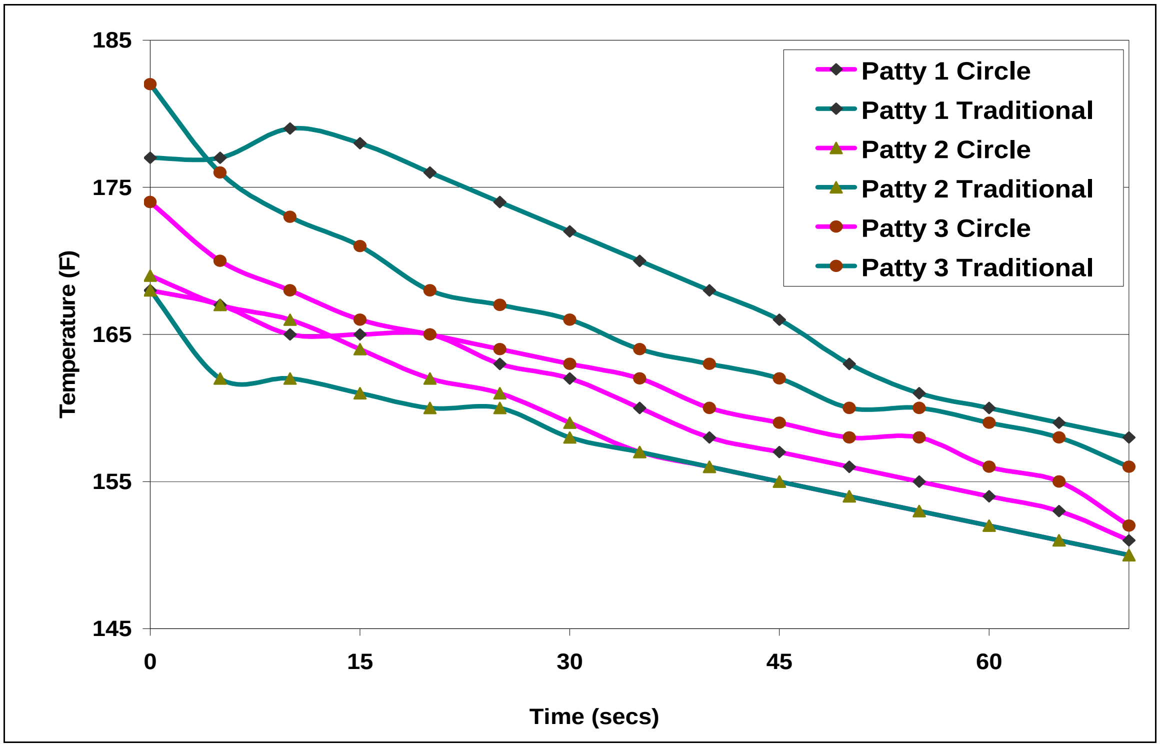

Figure 16. Temperature Measurement Comparison (transient)

Problem Recommendations

The key factor in beginning to control this temperature variation is factor uniformity. If a few of the aforementioned parameters can be controlled and kept constant, then the rest of the parameters can be optimized. For example, if parameters like oven burner condition, oven burner height, and number of burners operating could be held constant, then DOEs could be performed. If a DOE was performed for each product on both oven line 5 and oven line 6, operators would know the correct operating parameters for each product. Performing DOEs would likely lead to better understanding of what parameters make the biggest impact on product temperature and weight.

Before any other action is taken, however, Thermal Solutions recommends that an updated temperature measurement system be implemented. This temperature measurement system would include four parts. They are as follows:

1. A disc type thermocouple probe
2. An operator interface (i.e. Panel View)
3. A Programmable Logic Controller (PLC)
4. A host computer

These components would allow the temperature to be measured and logged in a more uniform fashion. This system would incorporate measurement timing, measurement recording, and data logging.

Currently, employees at Lopez Foods enter the handwritten logs into electronic form. They use this information for regulatory compliance and process improvement. This suggested system would eliminate manual data recording and manual data entry into a computer. The data would be logged to a network drive so that it could be accessed when needed to define trends in the oven system.

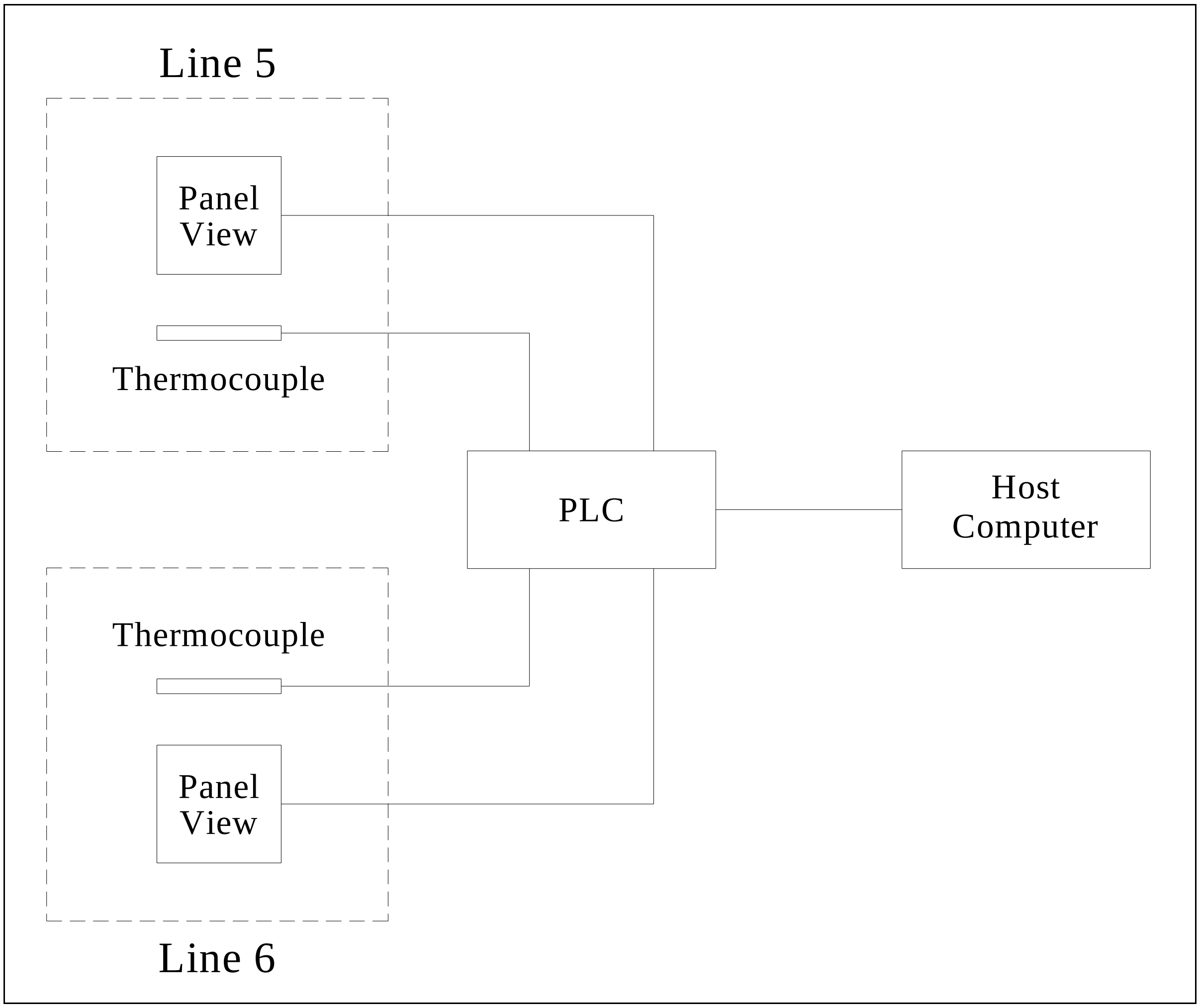

Figure 17. Temperature Measurement System

Figure 17 shows these components in a schematic diagram for the two oven lines. Each oven line has an operator interface (i.e., Panel View) and a thermocouple. These two components are connected to a PLC to relay commands and information. This information is sent from the PLC to the host computer where it can be stored in database form.

These two general recommendations would allow Lopez Foods to further understand and improve their process. The random nature of the current process mandates future testing to find the optimum settings for the process. When the process is controlled, then Lopez can expect more uniform product.

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Appendices

Appendix 1. September Patty Temperature Logs

A. Sample of Patty Temperature Logs

B. Excel Charts

C. Minitab Charts

Appendix 2. Oven Profile

A. November Excel Charts

B. March Excel Charts

Appendix 3. Room Environment Data

A. Room Temperature vs. Patty Temperature (Single Hobo Logger)

B. Room Environment Charts (Four Hobo Loggers)

Appendix 4. Thermal Camera Images

A. Sample Horizontal Patty Profile

B. Sample Vertical Patty Profile

Appendix 5. DOE

A. DOE Factor Identification

B. DOE Sample Run Set

Appendix 6. Designs

A. First Oven Profiler

B. Second Oven Profiler

C. Disc (single probe)

D. Disc (5 probes)

Meat Patty Temperature Variation

Sheetal R. Desai

Clara Rowden

Mohammed Siddiqui

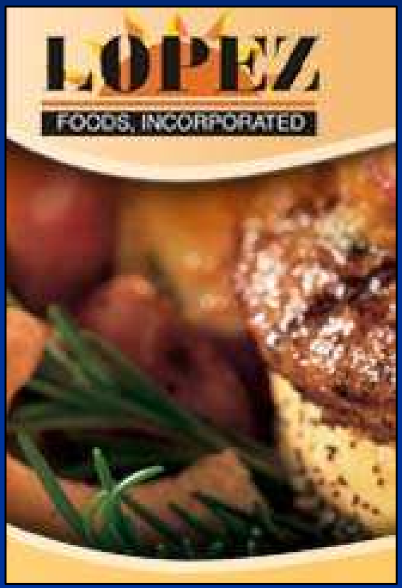
J.K. Evicks

BIOSYSTEMS & AGRICULTURAL ENGINEERING
Oklahoma State University

LOPEZ FOODS, INCORPORATED

Thermal Solutions

Client Background

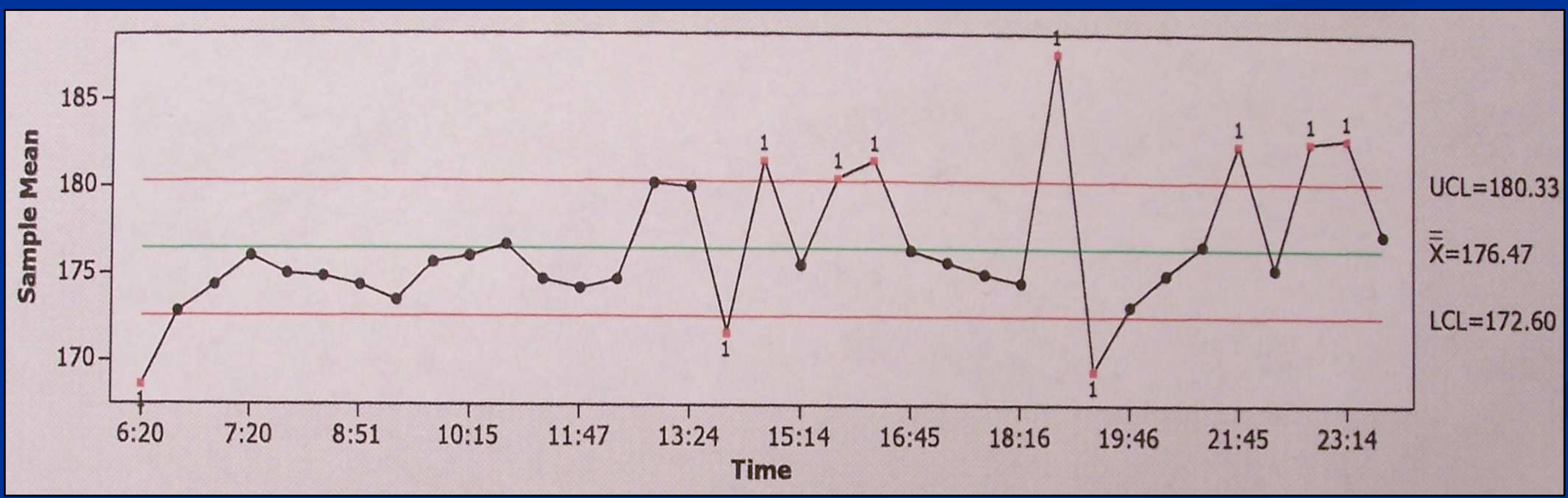


Lopez Foods, Inc.

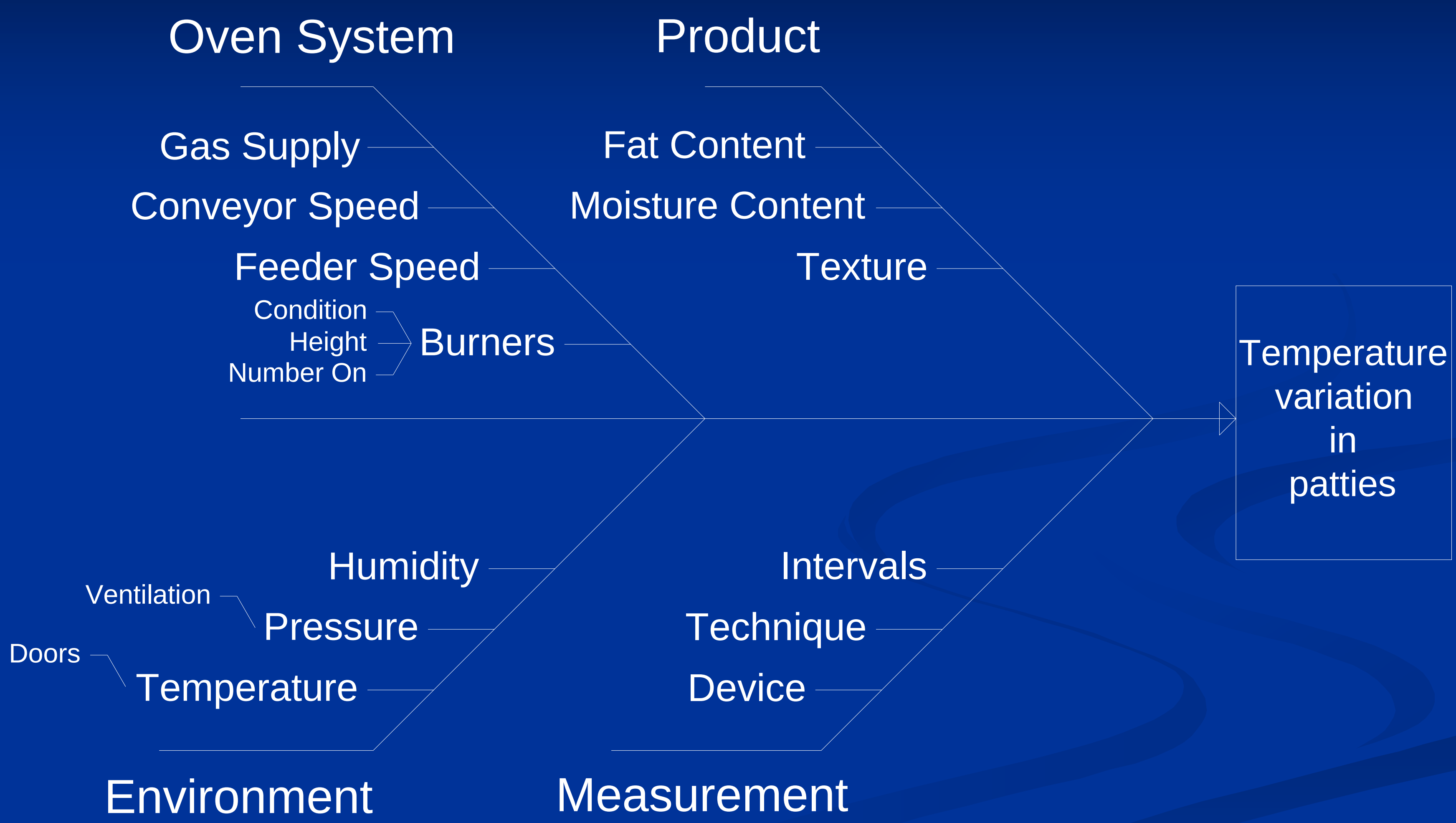
- Largest Latino-owned producer of beef and pork products in the U.S.A
- Products
  - Frozen, Partially Cooked, & Fully Cooked patties
- Processes
  - Grinding
  - Mixing
  - Cooking
  - Packaging

Problem Details

- Temperature variation: 30 ºF
- Overcooking → Weight Loss → Financial Loss
- USDA requirement: Hold 157 ºF for 10 seconds
- Undercooking → Health/Regulatory Issue



Factor Identification



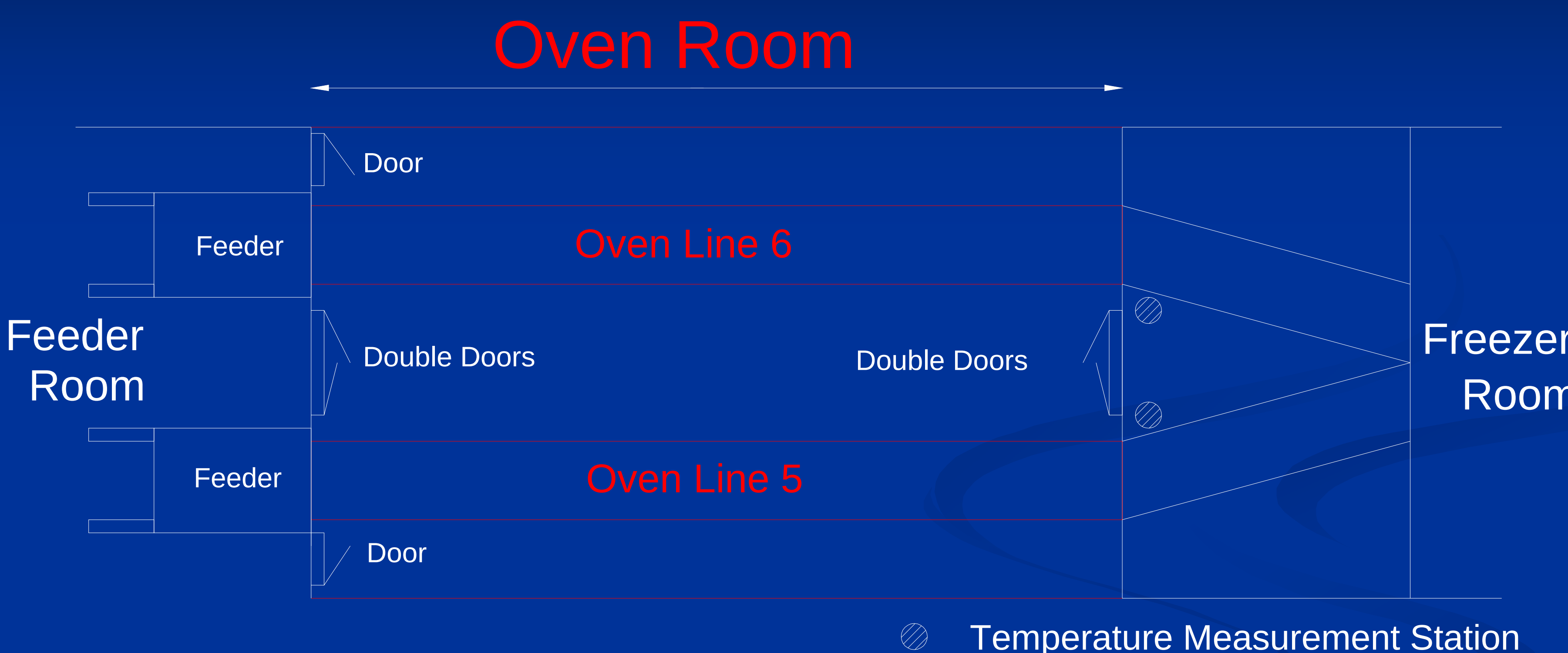
Thermal Solutions

Oven System

- Burners
  - Condition
  - Number On / Off
  - Height
- Formax speed
- Conveyor speed

Thermal Solutions

Environment



- Ventilation Imbalance
  - Decreases temperature
  - Increases humidity

Thermal Solutions

Temperature Measurement Technique

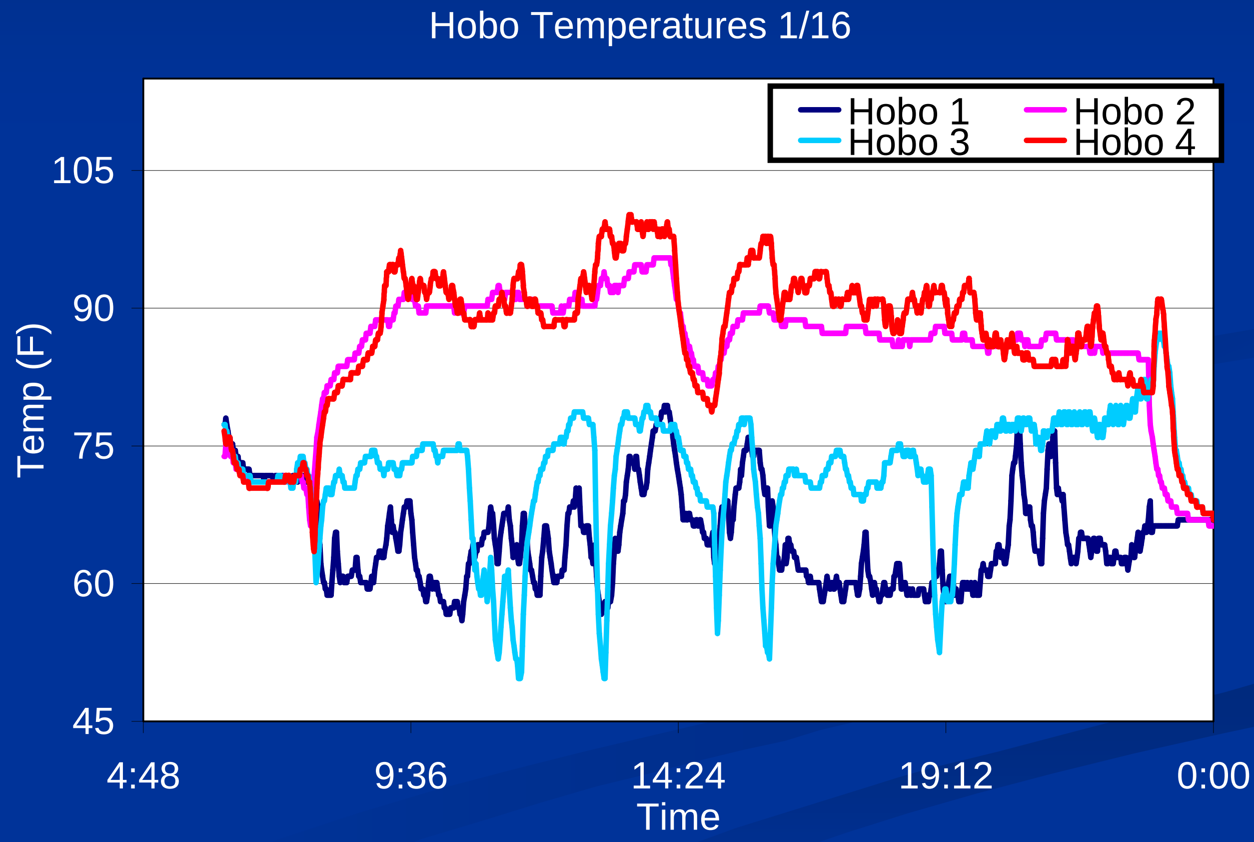
- Technique
  - Insert probe from side to center
  - Error due to probe positioning

Factor Testing

- Room Environment
- Oven Profile
- Thermal Camera
- Measurement Technique Comparison
- Design Of Experiment

Room Environment

- Onset Hobo® Data Logger
- Recorded 7 days of Temperature



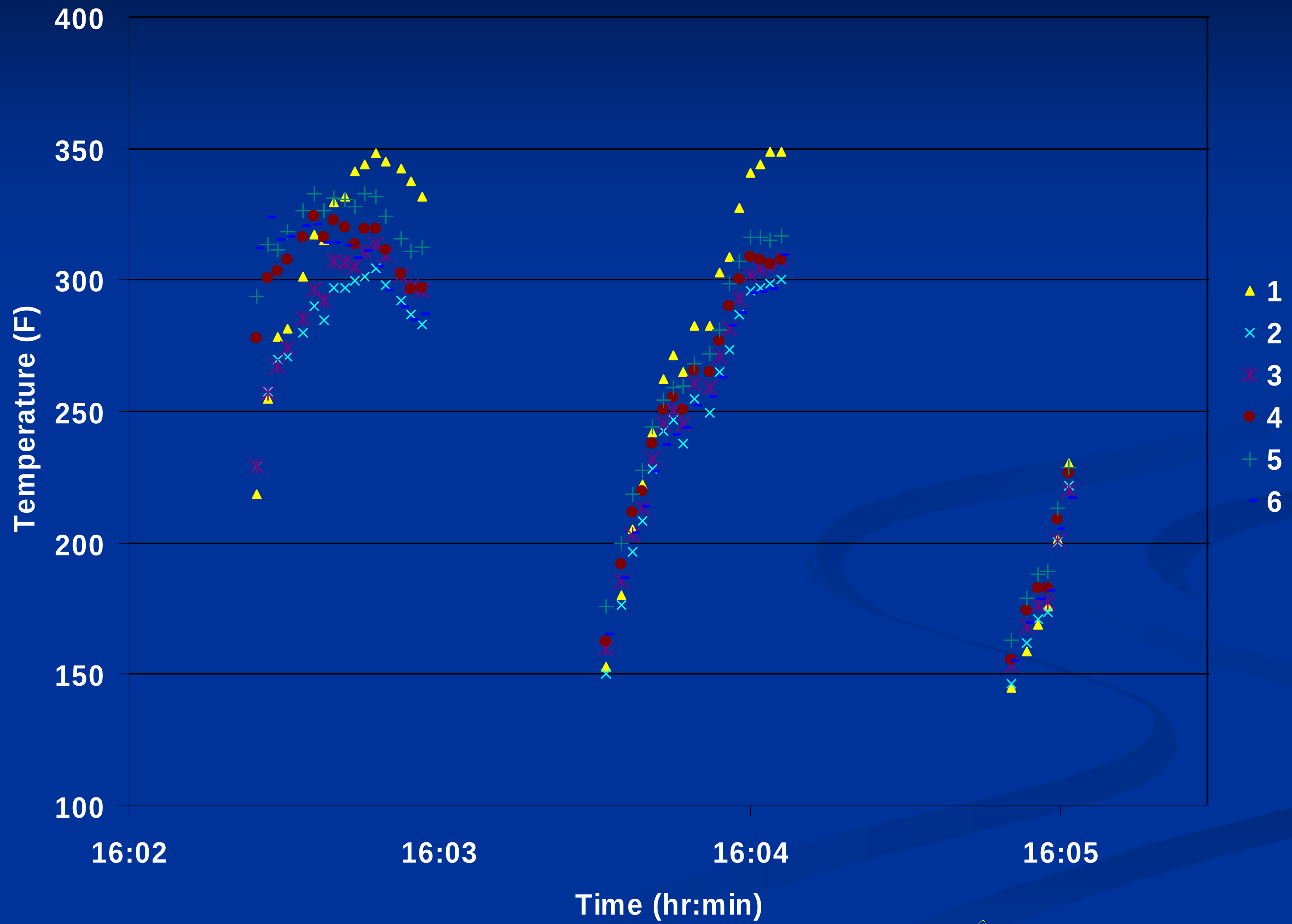
Thermal Solutions

Oven Profile

- Pace Scientific XR440
- Fluke Hydra II

Thermal Solutions

Oven Profile

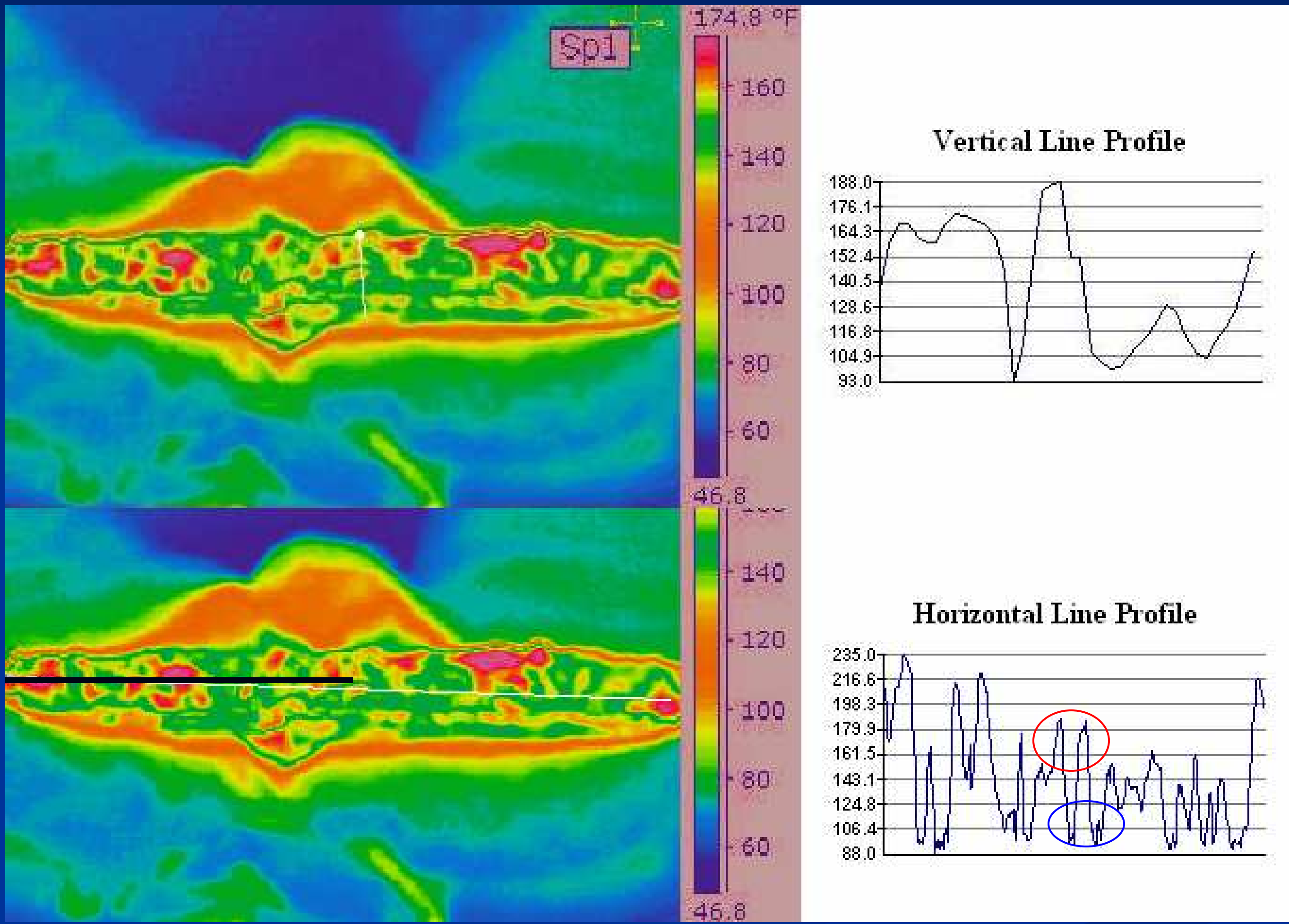


Thermal Solutions

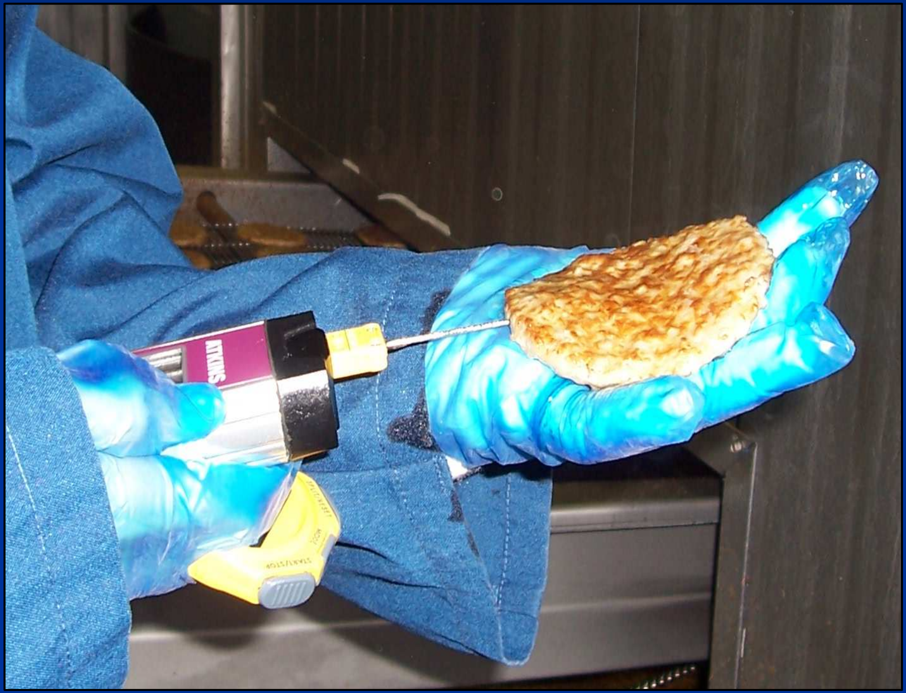
Thermal Camera

- ThermaCAM® E25
- Temperature profile of meat patty
- Used software for thermal image analysis

Thermal Camera



Technique Comparison

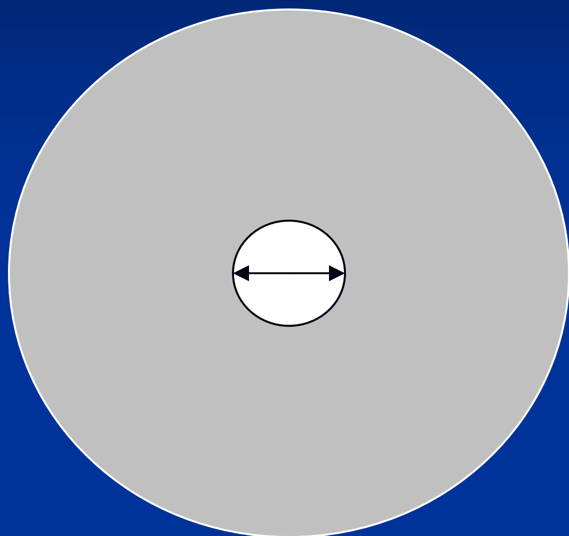


Side Probe

Disc Probe

Thermal Solutions

Technique Comparison



Disc Probe

- Repeatably reaches geometrical center of patty
- Reduced side to side variation

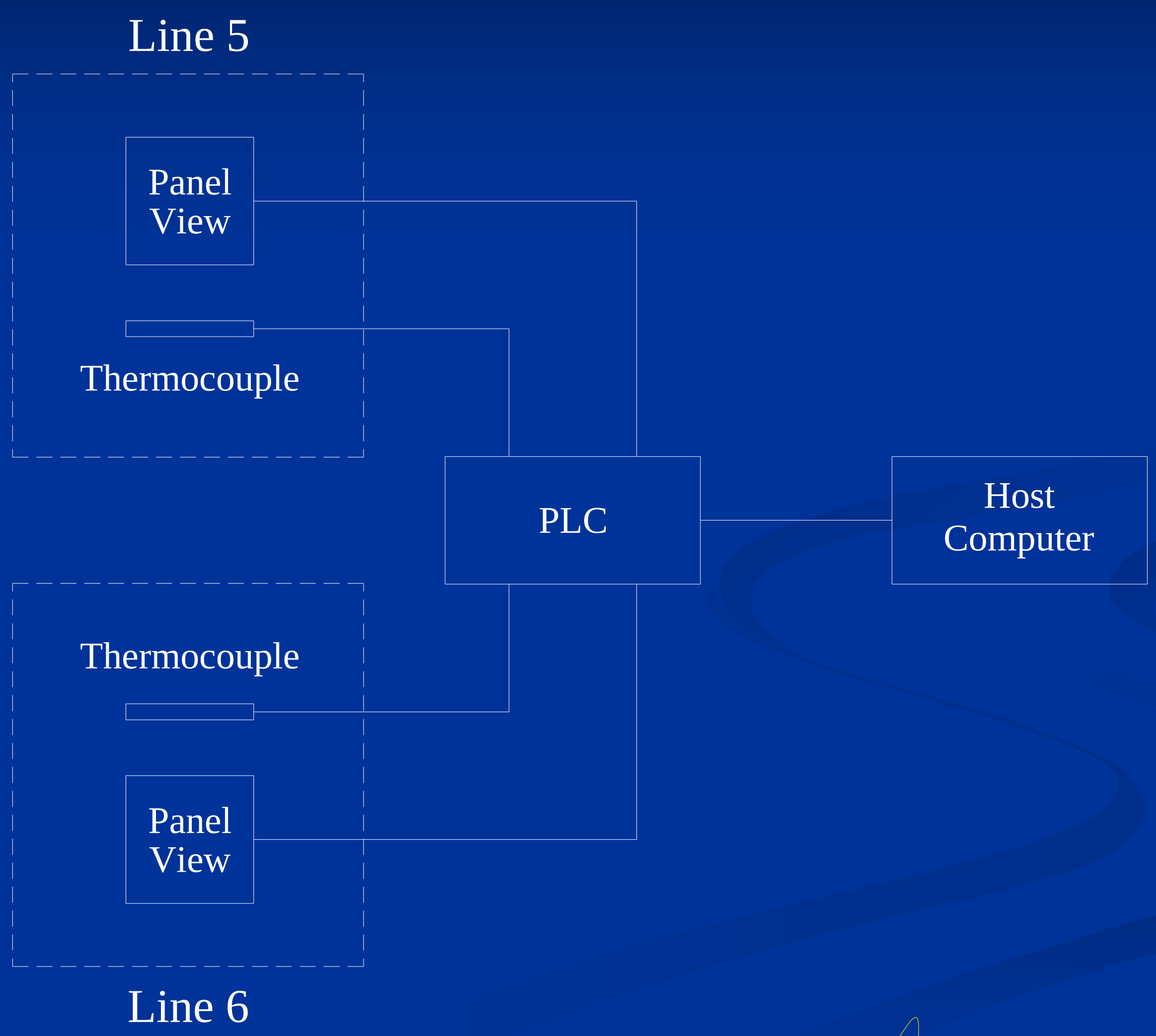
Recommendation

- Design of Experiment (DOE)
  - Statistical analysis of process
  - Optimize process variables
- Temperature measuring system
  - Reduce human error
  - Increase data availability and organization

Recommendation - DOE

- Optimizes process by:
  - Defining output variable
    - Patty Temperature
  - Determining impact of system variables
    - Conveyor speeds
    - Formax speed
- Example result:
  - $T = x_1 C_1 + x_2 C_2 + x_3 C_3 + x_4 F$

Recommendation – Temperature Measuring System



Thank You!

Lopez Foods, Inc

Dr. Kevin Nanke
Corporate QA Director

Ms. Lori Leininger
QA Team Leader

OSU

Dr. Paul Weckler
Senior Design Professor

Mr. Douglas Enns
Senior Applications Engineer

Mr. Scott Frazier
Graduate St. Industrial Engineering

Dr. Timothy Bowser
Food Processing Engineer

Mr. Wayne Kiner
BAE Lab Manager

Mr. Rajesh Krishnamurthy
Graduate St. Industrial Engineering

Any Questions?

Thermal Solutions

Oven Temperature Distribution

Fall 2005

Sheetal Desai

J.K. Evicks

Clara Rowden

Mohammed Siddiqui

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Mission Statement

Thermal Solutions is dedicated to satisfying client needs by developing innovative processing solutions.

Problem Introduction

Lopez Foods, Inc. is the largest Latino-owned producer of beef and pork products in the United States. The products processed in its Oklahoma City plant supply fast food and grocery retailers. During a final stage of the product processing, beef and pork products are cooked in custom-designed infrared (IR) ovens. No other version of these ovens exists in the industry.

Lopez Foods would like to increase the quality of their cooked meat products and reduce product loss. To help Lopez Foods attain this goal, Thermal Solutions is investigating factors that may be the cause of large temperature variations in the cooked meat patties. To monitor product quality, samples are taken from each patty across the oven belt every 30 minutes. Data from these cooked meat patties show that the internal temperatures of the patties range from 160°F to 190°F. This variation causes considerable safety, quality, and efficiency issues.

Statement of Work

Before any solution can be considered, the source of the problem must be found. This requires exploring all possible factors, eliminating improbable factors, factor testing, and testing analysis. Thermal Solutions first identified and listed factors that possibly affect oven temperature. After eliminating the improbable factors, Thermal Solutions then tested the remaining factors and analyzed the results. In summary, Thermal Solutions can only find a suitable solution once a suitable factor is identified.

Thermal Solutions' main objective is to find and control the factor(s) that cause 75 to 80 % of the temperature variation. Thermal Solutions will meet this objective by:

1. Finding the factor(s) as outlined above
2. Controlling the factor(s)
3. Implementing control measures
4. Testing the initial solution
5. Refining the solution if necessary

Literature Review

The following is a review of literature to find the root cause of the temperature variation. This review of process control, infrared ovens, temperature measuring devices, and safety and quality in cooked meat patties is provided to give insight to the problem.

Process Control

Any manufacturing process can improve. Plant personnel improve these processes by modifying the input and output of the system. One way to continually improve is to continually evaluate the process. When plant personnel find problems, they sometimes use a method called the DMAIC problem solving method. Bowser (2005) indicates DMAIC consists of Defining the problem, Measuring parameters, Analyzing data, Improving the problem, and Controlling the improvements. The method is easy to follow and can be iterated if results are not satisfactory.

Bowser (2005) states that cause and effect diagrams are visual aids that identify all of the possible factors influencing a particular outcome. Bowser also states that this diagram organizes factors into related groups and aids in the brainstorming process. It is also called a fishbone diagram because of its shape—a fishbone. It has a central spine with “bones” extending laterally from the spine. The “bones” or groups extending from the spine are generally large groupings like environment, equipment, personnel, etc. From these larger groupings, more specific factors branch out to describe the large groupings. Cause and effect diagrams can be a very useful tool in problem solving.

Control limits are boundaries that represent how well the process is controlled (NIST, 2005). If the data falls within the control limits set for the process, then it is in control, and vice versa. Based on a normal distribution, these limits are some multiple of standard deviations from the mean of the data. The NIST states that this multiple of standard deviations is usually three in the United States. If some of the data is outside of the control limits, corrective action such as DMAIC should be taken.

Correlations tell the relationships between two variables. Frahme (2004) says this is usually done via correlation charts commonly known as scatter plots. If measuring more than one variable, statistical software packages can offer analyses that might not have been seen before. Frahme says that even though correlations show relationships, they cannot prove cause and effect since two correlated variables may have the same root cause. Frahme concludes that correlations should merely be a guide to future research to narrow the search for the source of the problem.

Infrared Ovens

Infrared ovens are becoming popular in industries that heat biological materials because of their ability to rapidly raise product temperature. These ovens operate at the most efficient range of radiation for heat transfer—the infrared spectrum. (Find source)

The infrared spectrum includes all wavelengths between 0.75 – 1000 microns and is categorized into three parts:

1. Short-wave or near IR: 0.72 – 2 microns (3870 to 1180 C)
2. Medium-wave or middle IR: 2 – 4 microns (1180 to 450 C)
3. Long-wave or far IR: 4 – 1000 microns (< 450 C)

Lopez ovens most likely operate under far IR, the traditional method for heating biological materials (Fasina, 2003). To prevent charring of the biological material, IR oven temperatures stay within the 650-1200 °C range. IR also causes the surface of beef patties to lose moisture and fat. This loss results in the formation of a crust layer. However, according to Carnahan (2002) the lower cooking temperature of far IR results in less overall weight loss than hotter temperatures of shorter IR.

Temperature Measuring Devices

A variety of food thermometers are available in the marketplace. They are commonly categorized according to the type of sensor they use. Rund and Charlety (2005) identified three types of thermometers.

1. Thermocouple thermometers: measures temperature at the junction of the two wires located in the tip of the probe.
2. Thermistor thermometers: employs thermistors bounded in the tip of the probe typically with epoxy.
3. Bimetallic coil thermometers: contains a helix coil in the probe made out of two different metals that are bounded together. The metals have different rates of expansion

Lopez Foods uses a thermocouple thermometer (Atkins model 386) to measure the internal patty temperature.

Food thermometers must be properly calibrated. Therefore, the accuracy of the reference thermistor is very important. The accuracy of the temperature read depends on the accuracy of the thermometer. Rund and Charlety (2005) state that a thermometer should be calibrated:

1. everyday
2. after it is dropped
3. between uses of differing extreme temperatures

Meat Safety and Quality

Safety and quality are two main concerns of the food industry. Food poisoning, cross-contamination, and food-born illness demand the food processors to process meat at conditions set by recognized organizations like the Food and Drug Administration (FDA) and United States Department of Agriculture (USDA). The FDA states that the standard internal cooking temperature at which all the pathogens in a meat patty are destroyed is 160 ºF (FSIS, 2003).

The complexities involved in the heterogeneous mixture of meat and changing environment makes maintaining these standards a challenging issue. A single meat patty undergoes many physical and chemical changes during the cooking process. Non-uniform distribution of fat, protein, and water in the patty regulates the rates of heat and mass transfer. The most commonly observed physical change is likely the decrease in diameter and thickness due to drainage of fat and water. This change enhances the variation heat transfer throughout the cooking process (Singh, R.P., 2005).

Color, texture, or other visible signs are misleading factors to the doneness of a patty. Research done by USDA (2003) shows that one out of every four hamburgers turns brown before reaching the safe internal temperature (FSIS, 2003). If the patty reaches 160 ºF internally, the meat is safely cooked even if the meat is pink inside. The most appropriate technique to judge the doneness of a patty is to measure the internal temperature.

In a large scale cooking process, the time a patty stays in the oven must be controlled. If the belt speed is fast, a thin crust forms on the outer surface of the patty. This surface makes the patty stiff and prevents further cooking. The speed of the conveyor must correspond to the heat supplied and cooking time (Singh, R.P., 2005).

Customer Requirements

Lopez Foods stated that Thermal Solutions needs to find the main parameter(s) that can be managed to solve 75 – 80% of the temperature variability. Once that parameter is found, it must be controlled. Eliminating this variability will make the process much more predictable and the product more uniform.

Possible Factors

After visiting Lopez Foods, Thermal Solutions composed a list of possible factors that may cause the non-uniform heating of the meat patties. A cause and effect diagram is shown in Figure 1 to show how these factors are related.

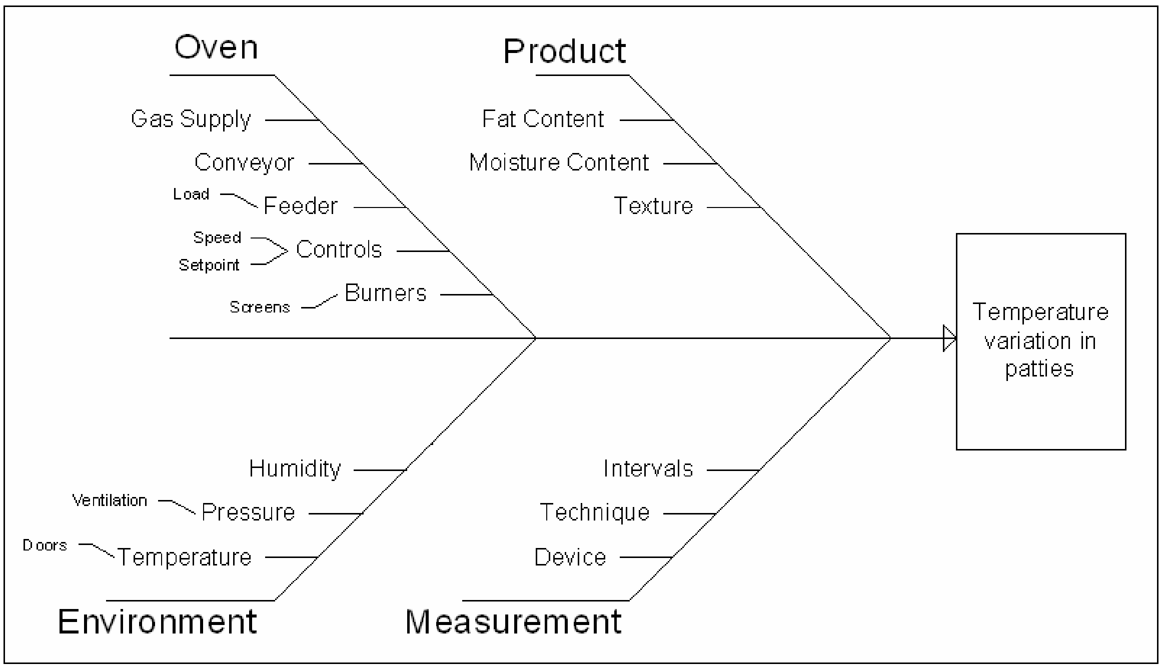

Figure 1. Cause and Effect Diagram

Environment

The oven room environment is the first parameter Thermal Solutions investigated. The oven room is located between the meat grinding room and the freezer room which are both at very low temperatures. The oven room's ventilation system operates at a negative pressure; less air is pumped into the room than is ventilated out. This unbalanced air pressure leads to a large rush of cooler air when the doors connecting the oven room to the 45°F grinding room are opened. These frequently opened double doors lead to heat loss and increased humidity in the oven room over a short period of time. Figure 2 shows the oven room layout. These continuously changing factors may affect the cooking process.

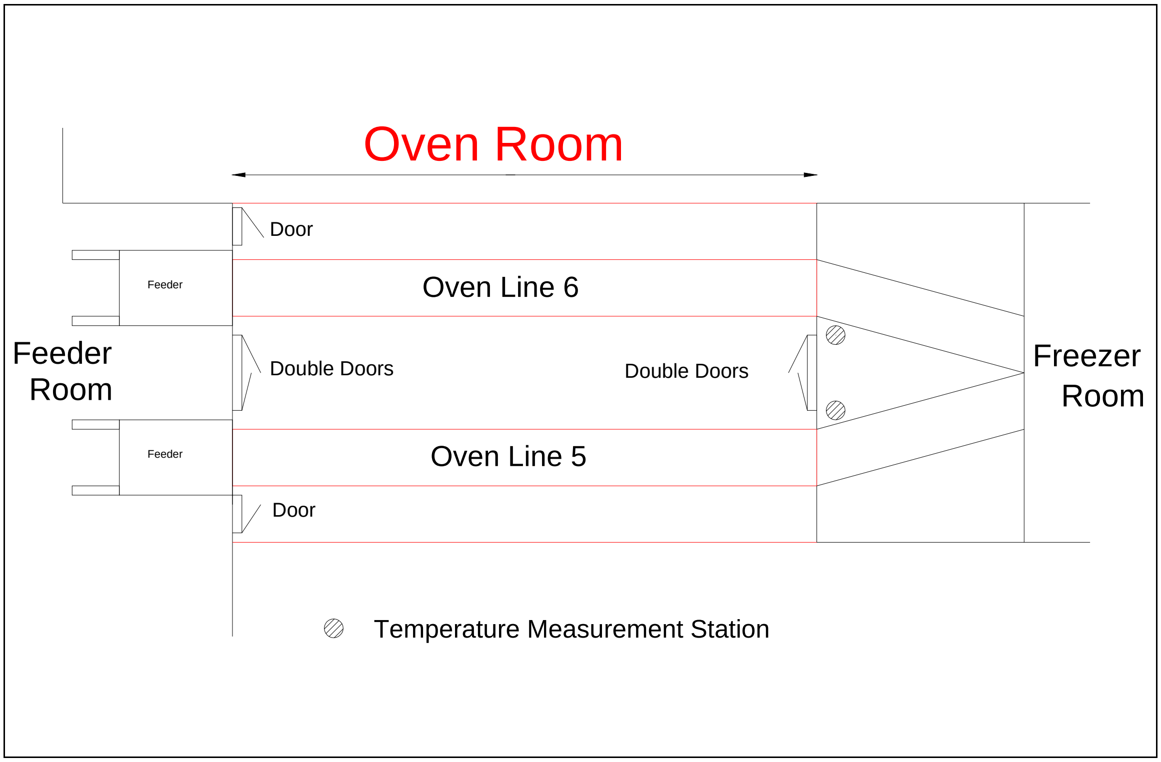

Figure 2. Oven Room Layout

Product Composition

Irregularities in the meat patty composition may cause different meat patties to heat at different rates. For example, a patty with a higher fat or moisture content requires a longer time to cook because its physical properties are different than that of leaner, drier meat. Since the original meat Lopez receives varies continually in composition, Lopez grinds varying amounts of fat and moisture into the meat ensure a uniform patty composition. Even after mixing, Lopez still cannot fully control uniform composition of each meat patty.

Oven

Various components of the oven can greatly influences the temperature of the meat patties. The oven components of concern are the gas supply, conveyor, feeder, controls, and burners. The gas supply controls the amount of heat the oven supplies. Variations in pressure or energy value of the gas cause a direct variation in oven temperature.

The rate of the patty feeder causes temperature changes according to the meat load in the oven. The speed control of the conveyer belt also changes the rate at which the patties go through the oven. Technicians alter the controls of both the feeder and conveyor line continuously through the day based on the temperature measurement readings.

The burners' individual performance and condition relates to the performance of the entire oven. The conditions of each oven burner vary dramatically from good condition to blacked out. A few even catch fire while in operation and are left to extinguish themselves over time. Lopez technicians work each day repairing and replacing these burners. At any given time on any day, the burners' heat output is not the same. The significance of these differences is currently unknown.

Measurement Method

Temperature measurement in itself could be a significant factor. For example, significant errors may come from miscalibration or other device errors. In addition, the temperature recording technique used may also be a contributing factor. As noted earlier, the FDA states that the internal temperature of the meat patty must be at least 160 °F. This temperature reading must be taken at the geometric center of the patty because it is the point that takes the longest to reach

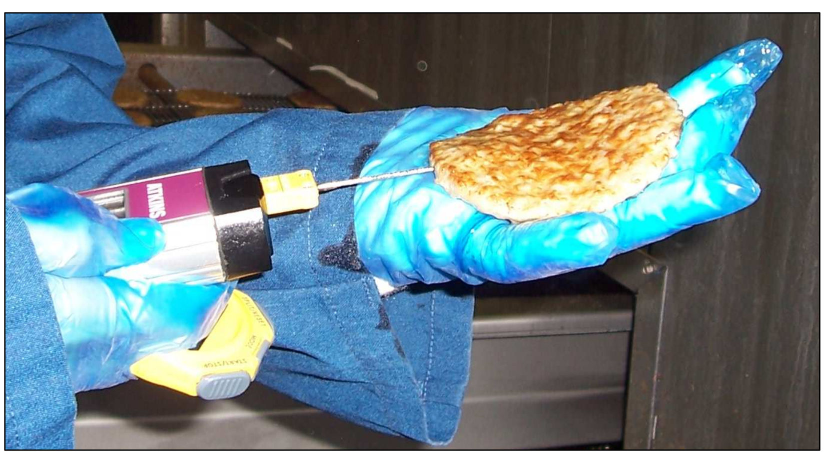

Figure 3. Traditional Temperature Measurement Technique

the critical temperature. Employees at Lopez Foods insert the thermocouple probe into the side of the patty for 10 seconds to read the temperature at the center of the patty. Figure 3 shows an employee measuring the patty temperature. The accuracy of this technique is questionable because it is very hard to reach the actual center of the patty with the temperature probe.

Factor Determination and Testing Methods

This large list of possible factors must be narrowed. To accomplish this, Thermal Solutions first obtained patty temperature measurements of the patties cooked by the two ovens. This initial data, displayed in Figure 4, shows that average patty temperatures from both ovens vary at the same time. This trend indicates that the main factor must affect both ovens. Therefore, factors such as burner condition, which are specific to each oven were eliminated.

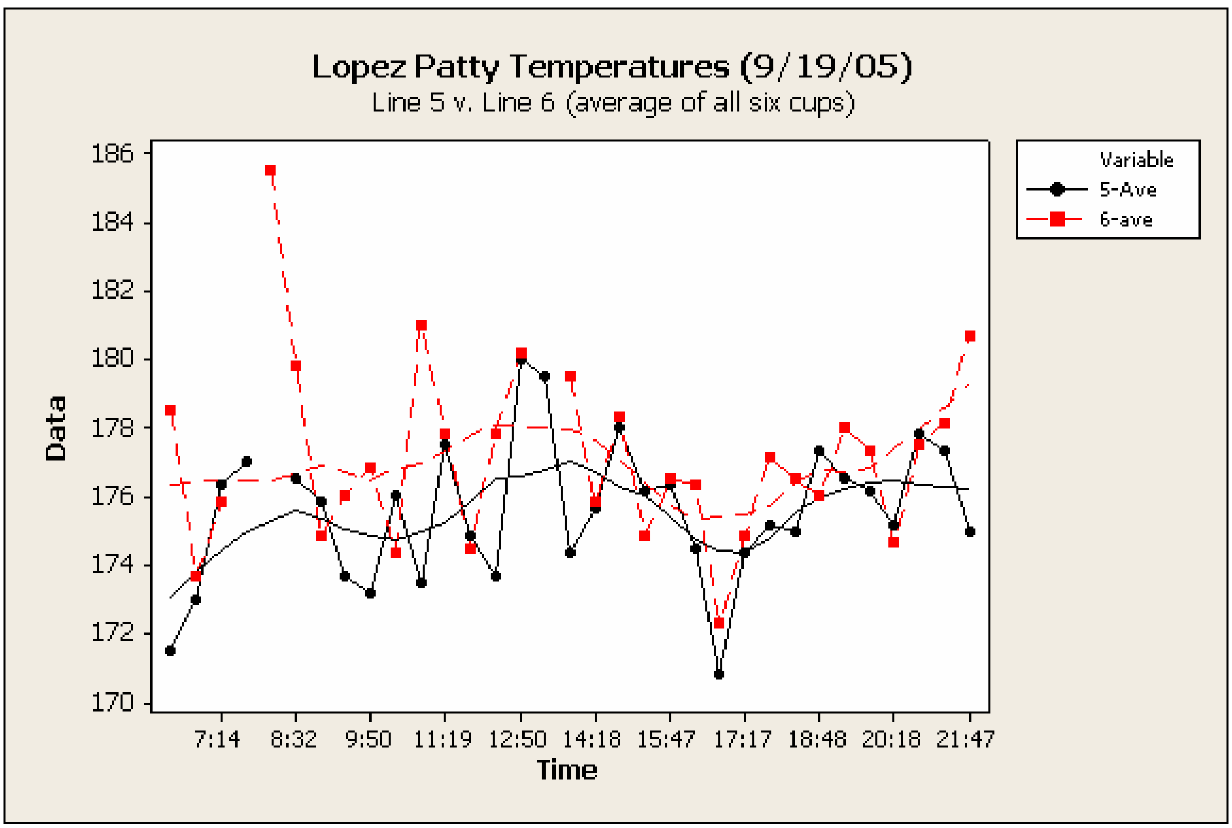

Figure 4. Oven Correlation

Thermal Solutions also gathered data on the product composition before selecting factors to test. This investigation showed that the composition of the product did not have the variability as previously thought: fat variation is only 2% and the added water content is only 3%. These figures do not warrant the variability seen in the temperature distribution, so variation in the product composition was also eliminated.

From the remaining list of factors, Thermal Solutions chose to evaluate factors that were deemed to have the most impact and were easiest to test. These chosen factors are temperature variation in the oven, environmental variation, and temperature measurement technique.

Oven Temperature Variation

Dr. Timothy Bowser, a technical consultant for Thermal Solutions, suggested a profile test to determine how temperature varies across the length and width of the oven. Figure 5 shows the apparatus Thermal Solutions used to profile the oven.

Figure 5. Data Logger Apparatus

A Pace Scientific XR440® data logger was placed inside an insulated enclosure in the apparatus in Figure 5 to prevent heat damage to the instrument. Four wires covered in PFTE tubing extended from the logger enclosure to four thermistors. These thermistors represent four channels across the conveyor belt.

This data logger design was only partially successful. The oven burners were much lower than expected and hindered testing of all three sections of the oven. Therefore, only the first section of the oven was profiled.

Environmental Variation

Unlike other factors, the room environment is not measured regularly. Room environment varies due to the oven load and air flow in and out of the room. An Onset Hobo® U12-013 data logger recorded temperature and relative humidity every minute for a one week period. This test was designed to determine the effect of room environment on patty temperature.

Temperature Measurement Comparison

To determine the accuracy of Lopez's temperature measurement technique, Thermal Solutions measured the temperature of patties with two different devices at the same time. The first device was the standard thermocouple probe that Lopez uses (Refer to Figure 3). The second device was a custom-made thermocouple probe designed by Dr. Timothy Bowser (Figure 6). This device ensures that the temperature is measured at the center of the patty by fixing the thermocouple height in the device.

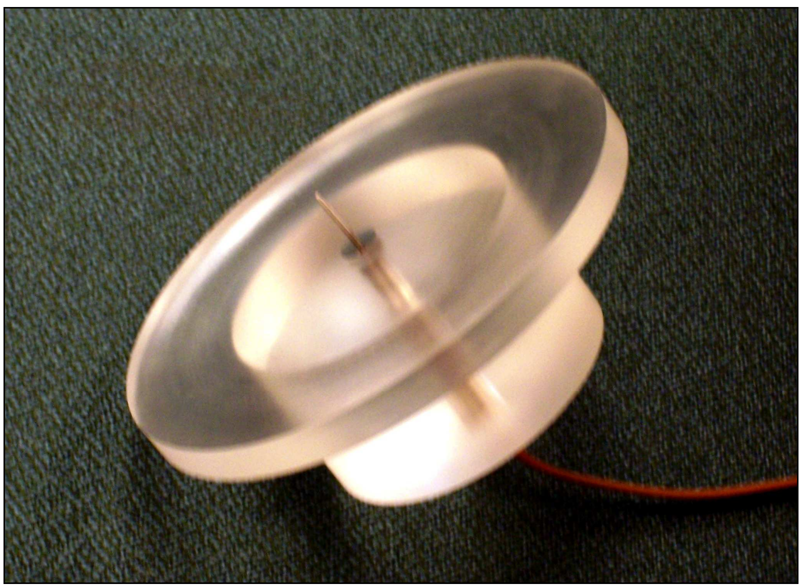

Figure 6. Disc thermocouple probe

To ensure accurate testing, Thermal Solutions first tested the calibration of the two temperature devices. Thermal Solutions employed two different tests to compare the traditional method to the new disc method. During the first test, both thermocouple devices measured temperature after 10 seconds within the same patty. This process was completed for approximately 30 patties to find the difference in instantaneous measurements.

During the second test, Thermal Solutions measured the temperature decrease of patties every five seconds for a one minute period. Again, like the previous test, both probes were inserted into the same patty at once. Data for three patties was obtained.

Factor Test Analysis

Oven Profile

The data acquired from the oven profile provided meager results. Figure 7 shows the data as it appears in MS Excel. Since the data logger was only in the oven for less than one minute, the data from the different thermistors appears as peaks. The first three set of peaks represents three passes down the first section of the oven with the doors open, while the seconds set represents three passes with the doors closed. Channel one (closest to aisle) is consistently lowest in temperature with both the doors open and closed. Channel two is consistently highest in temperature with the doors open, but lower than three and four with the doors closed. Channel three and four (closest to wall) were very close to each other in temperature in both runs with three being slightly higher. Both were lower in temperature than channel two with the doors open, but highest with the doors closed.

The most significant feature of this data is the temperature difference between the channels within each peak. These differences range from 30-50 °F. This shows that there may be a significant temperature variation across the width of the oven. However, more complete testing is needed to confirm this.

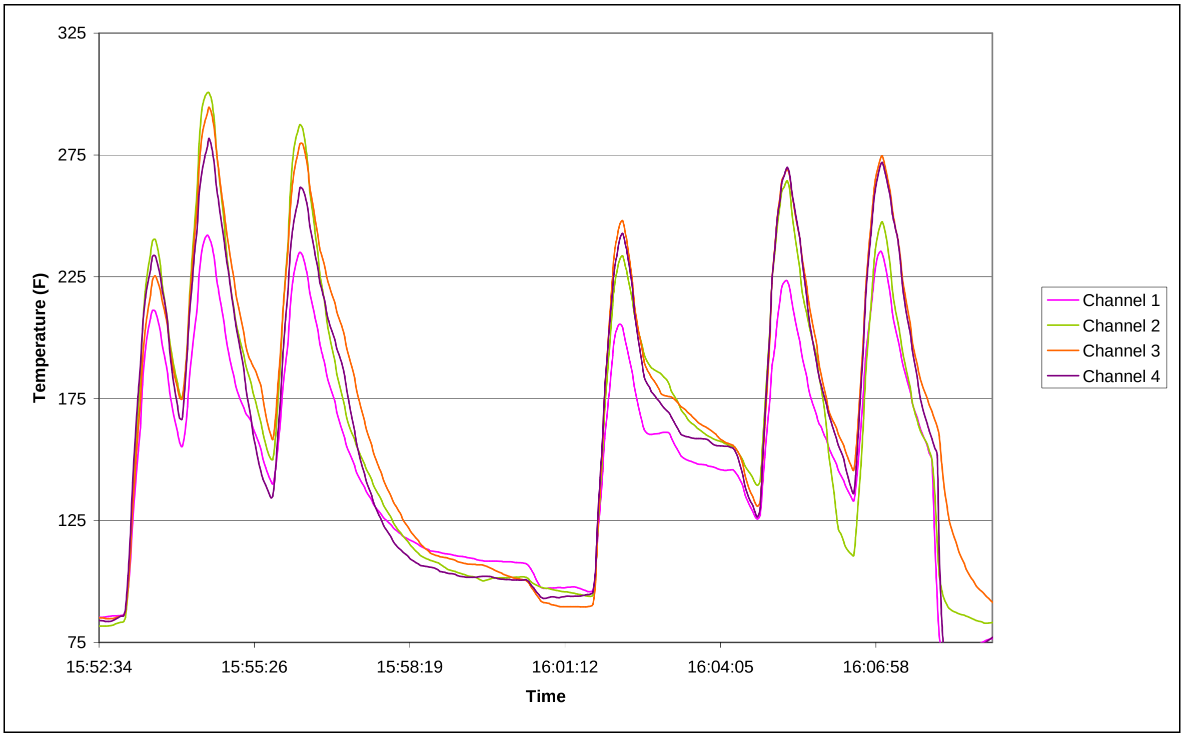

Figure 7. Oven Temperature Profile

Environmental Variation

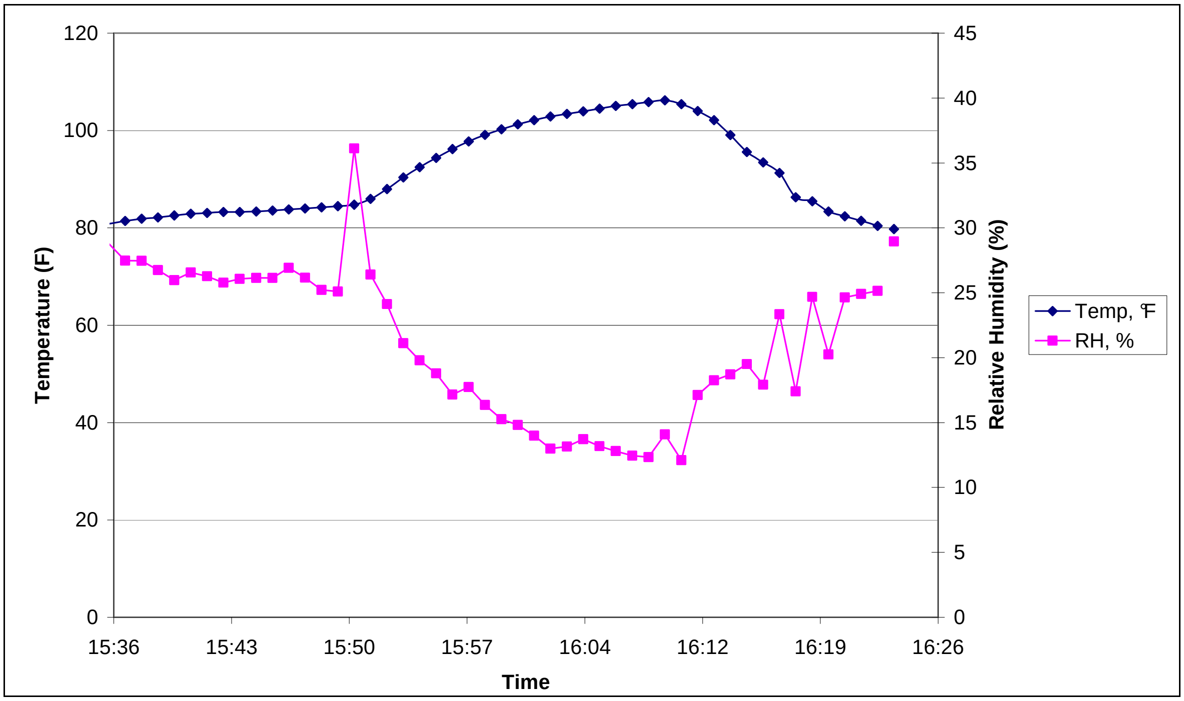

Figure 8. Door Effects on the Environment

As stated earlier, room environment varies due to the oven load and air flow in and out of the room. For example, when the door is closed, the temperature may increase 20 degrees. Figure 8 on the previous page shows the temperature rise and relative humidity drop as the door is closed (at time 15:50).

Figure 9 compares the environmental room data to the corresponding patty temperature measurements. By analyzing this data, Thermal Solutions determined that overall environmental changes in temperature and relative humidity do not affect patty temperatures.

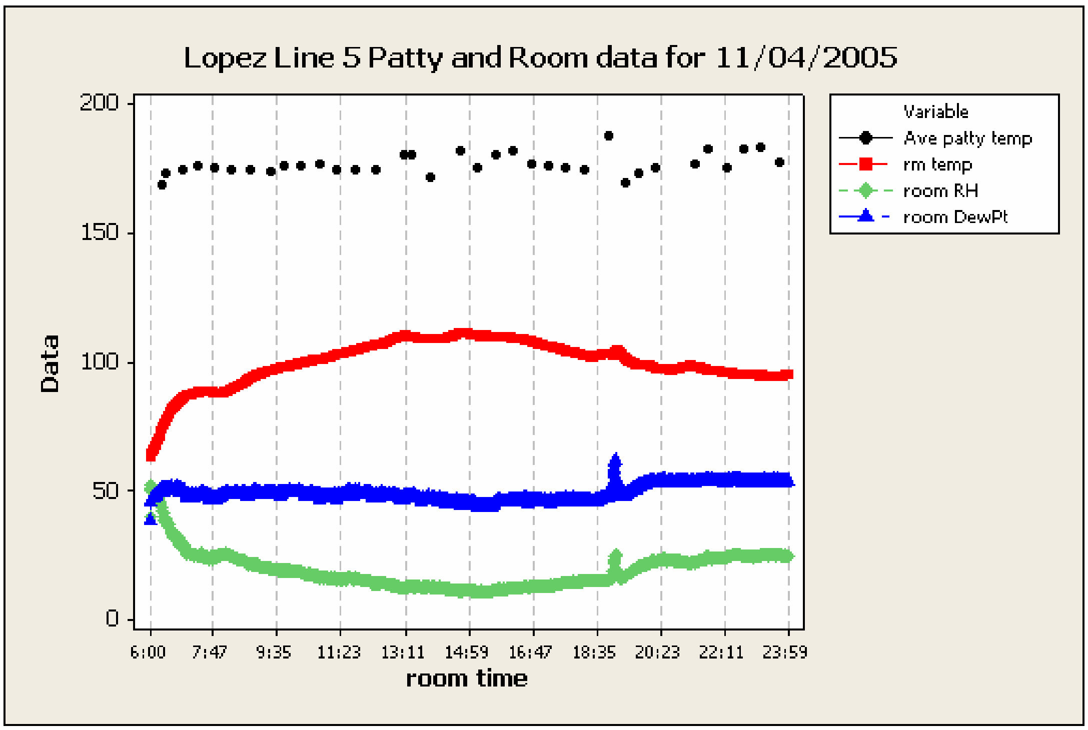

Figure 9. Patty Temperature vs. Room Environment

Measurement Technique Comparison

As stated earlier, Thermal Solutions compared the temperature measurement devices. Figure 10 shows that the data for the each of the measurement devices seems to be very similar. For example, when the temperature recorded on one device is higher than average, then the temperature recorded on the other device tends to be higher than average. However, the temperature difference in the two devices ranges from 2 °F to 12

°F. This data suggests that the disc-type probe is fairly constant in temperature measurement, while the traditional side probe varies in temperature.

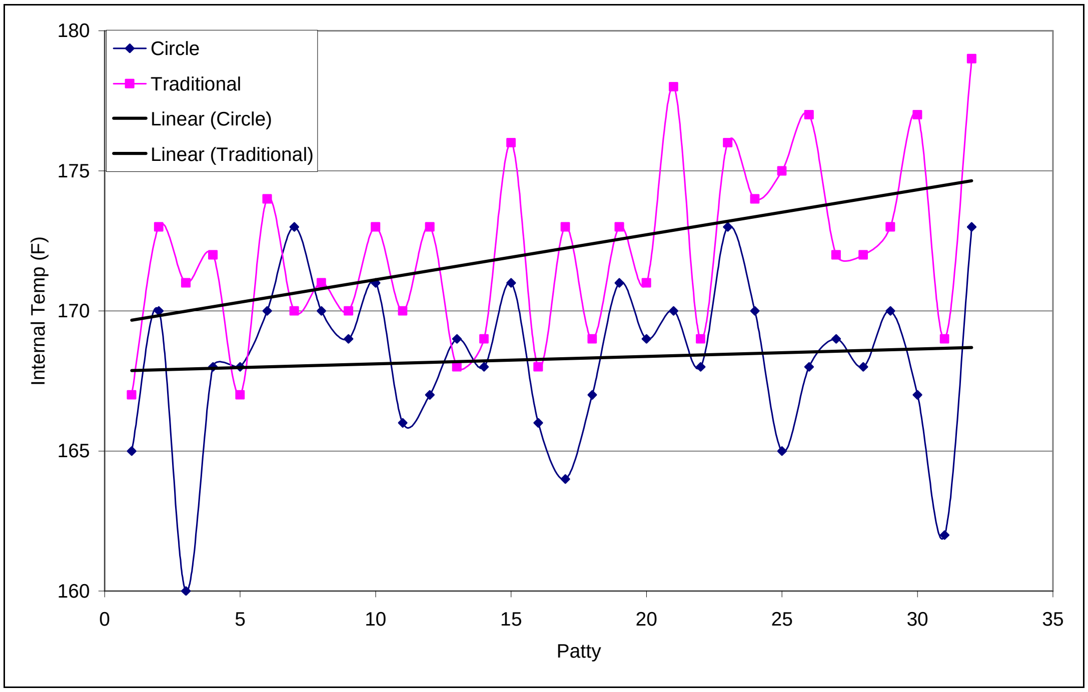

Figure 10. Temperature Measurement Comparison (instantaneous)

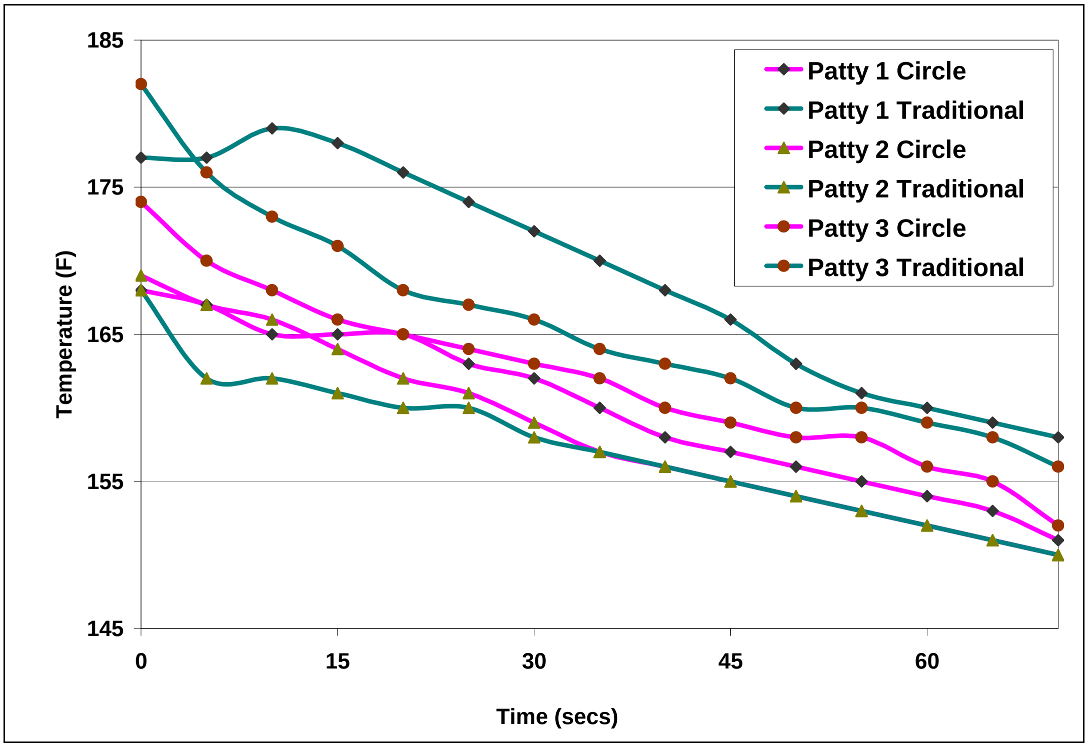

Figure 11. Comparison of Measurement Methods

Thermal Solutions

The result of the transient temperature measurement comparison is shown in Figure 11 on the previous page. Though this comparison used only three patties, this data suggests that the disk probe is more repeatable than the traditional side probe. More testing will be completed to prove or disprove these theories.

Problem Solution

Currently, the source of the problem is yet to be identified. The problem is likely not very complicated, but it is currently unknown. It is likely the problem can be improved by altering one of the following: the doors, the control system, the ventilation system, or the temperature measuring system. Future data collection and analysis will identify the key factor so that a suitable solution can be implemented.

Task List

Please see Appendix 4.

Project Schedule

Please see Appendix 5 for a complete Gantt Chart.

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Appendices

Appendix 1. September Patty Temperature Logs

- A. Patty Temperature Logs
- B. Excel Charts
- C. Minitab Charts

Appendix 2. Oven Profile

- A. Excel Charts

Appendix 3. Room Environment Data

- A. Patty Temperature Logs
- B. Minitab Charts

Appendix 4. Task List

Appendix 5. Gantt Chart

Meat Patty Temperature Variation

Sheetal R. Desai

J.K. Evicks

Clara Rowden

Mohammed Siddiqui

BIOSYSTEMS & AGRICULTURAL ENGINEERING
Oklahoma State University

LOPEZ FOODS, INCORPORATED

Thermal Solutions

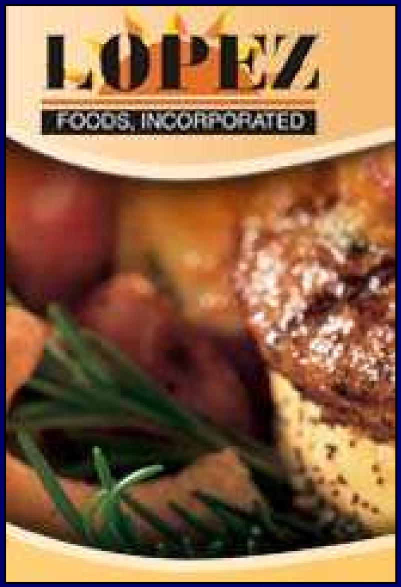
Client Background

Lopez Foods, Inc.

- Largest Latino-owned producer of beef and pork products in the United States
- Operates two food processing plants
  - Carneco Foods — Columbus, NE
  - Lopez Foods — Oklahoma City, OK
- Supplies major fast food retailers and grocers

Thermal Solutions

Client Background

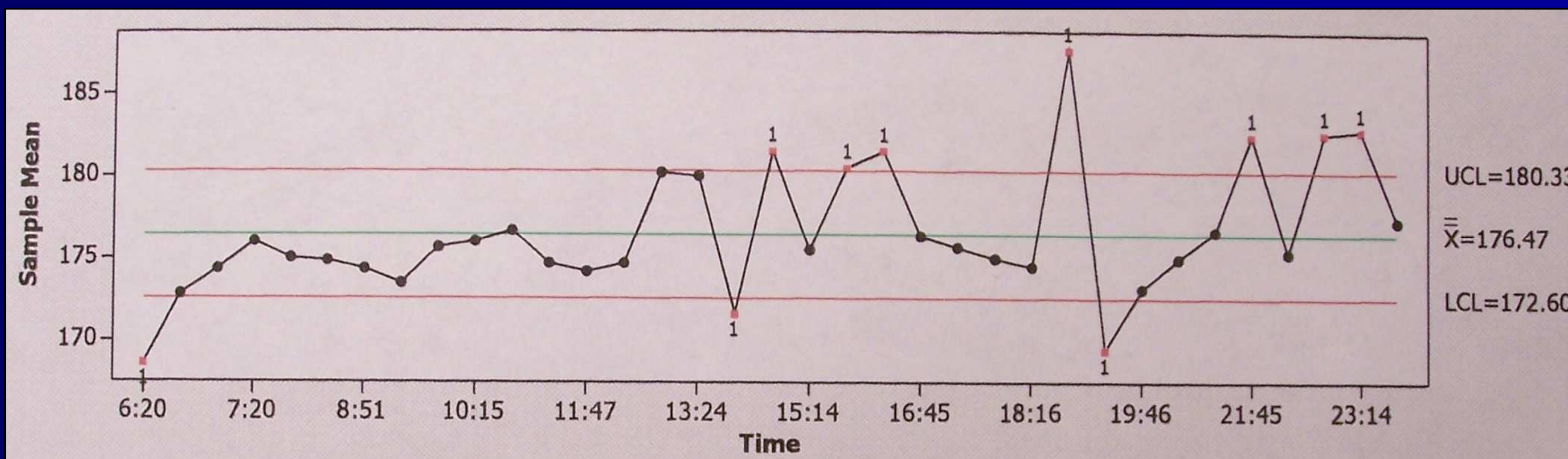


- Products
  - Beef (250 tons/day)
  - Sausage (140 tons/day)
- Processes
  - Grinding
  - Mixing
  - Cooking
  - Packaging

Thermal Solutions

Problem Details

- FDA requirement: 158 ºF
- Temperature variation: 30 ºF



Thermal Solutions

Problem Details

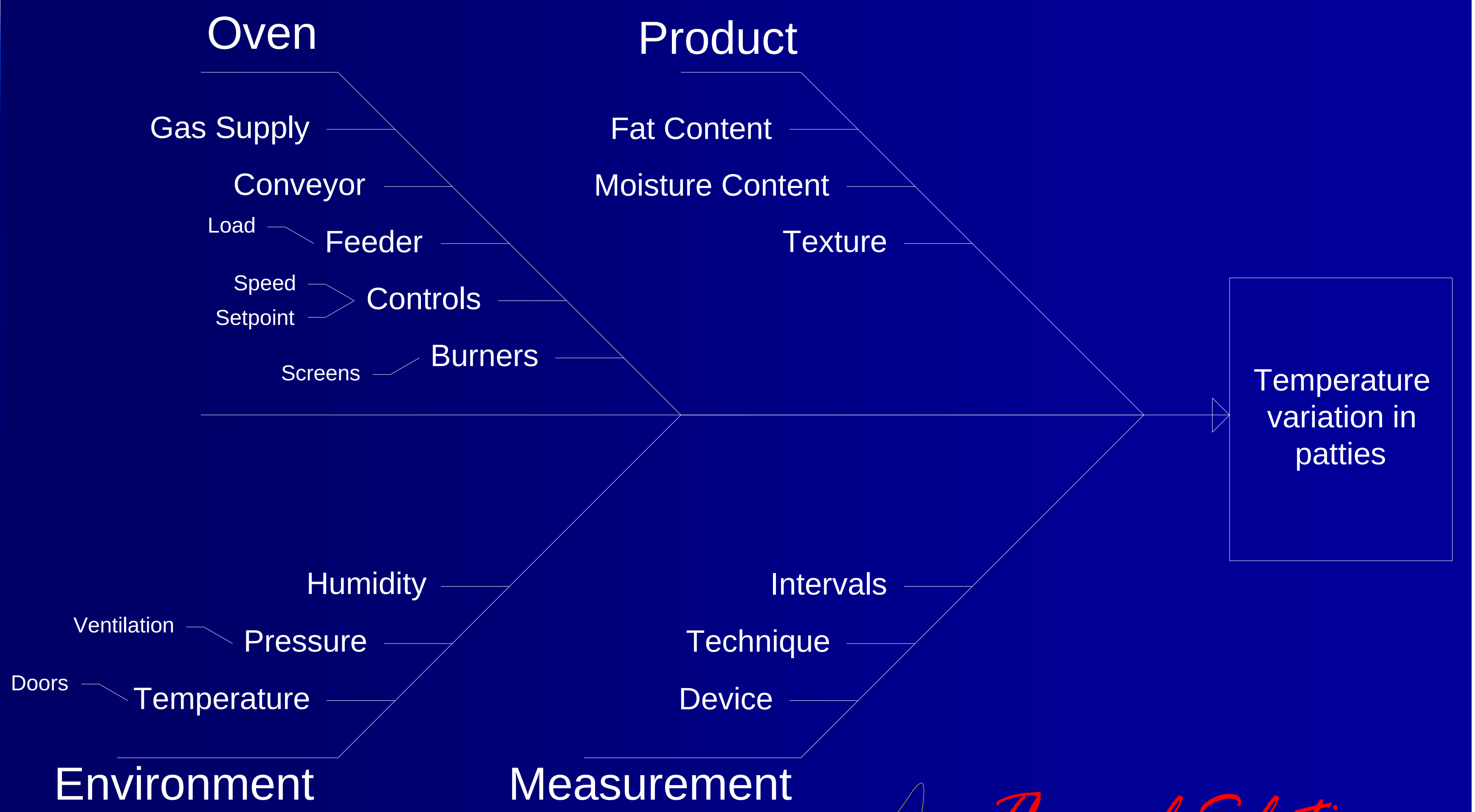
Overcooking	Undercooking
↓	↓
Moisture Loss	Health/Regulatory Issue
Fat Loss	
Size Loss	
↓	
Financial Loss	

Client Requirements

- Reduce variability by 75 – 80 %
- Achieve lower average temperature
  - 162 – 165 ºF

Thermal Solutions

Factor Identification



Thermal Solutions

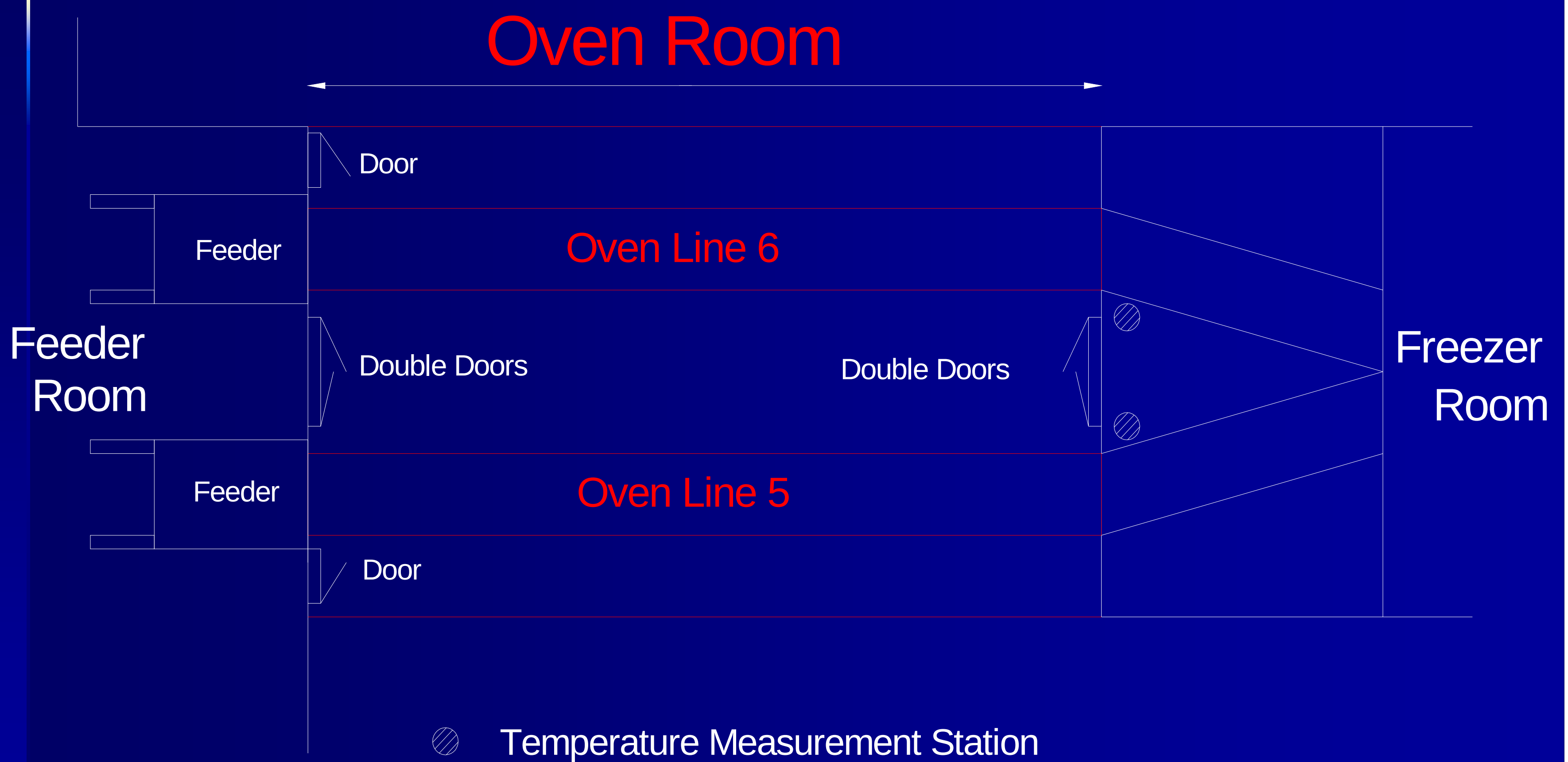
Oven System

- Open Design
- Burners
  - Catch fire
  - Burn out
- Conveyor speed
- Feeder speed

Raw Product

- Fat Content – 2% Variability
- Moisture Content – 3% of the batch

Environment



Thermal Solutions

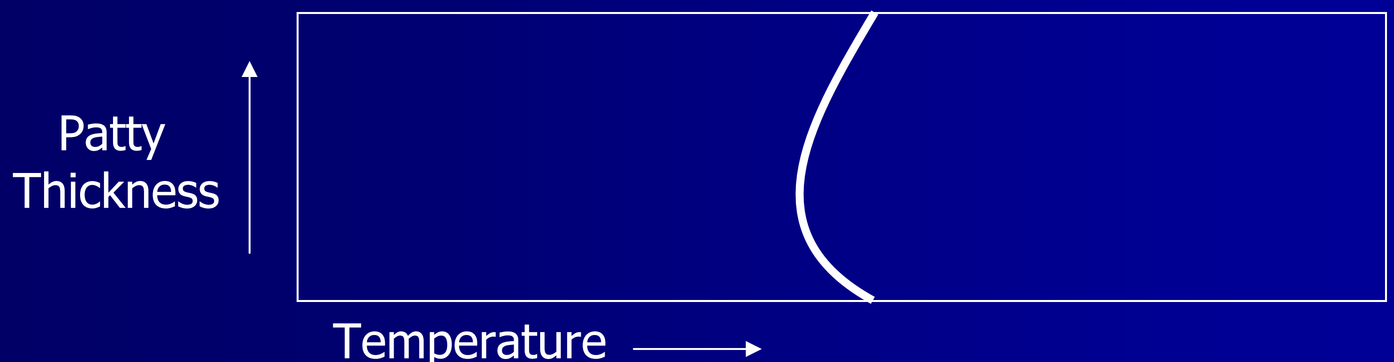
Environment

- Ventilation
  - 900 cfm in, 1000 cfm out
- Door usage causes
  - Decrease in temperature
  - Increase in humidity

Temperature Measurement Technique

Temperature Measurement Technique

- Technique
  - Insert probe from side to center
- Positioning
  - Error due to probe positioning

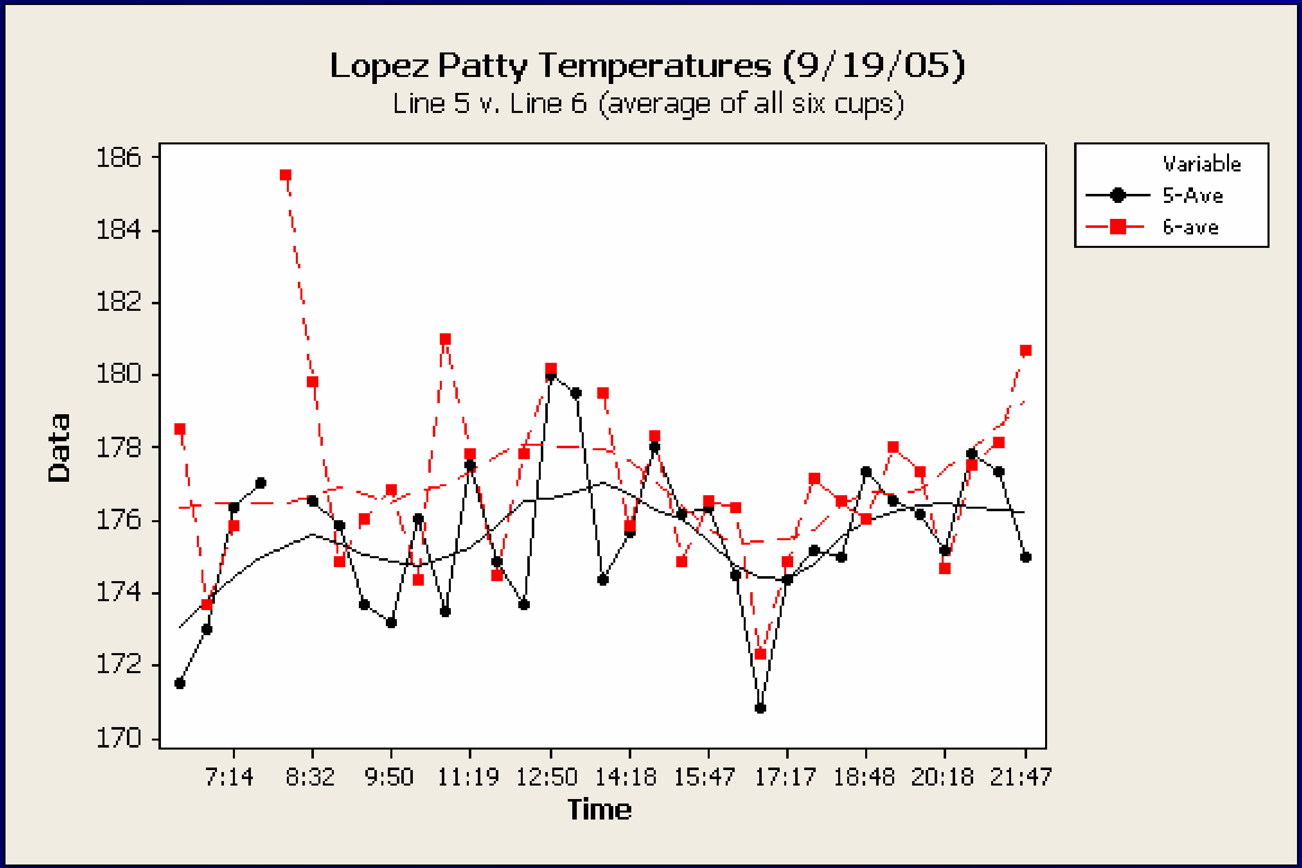


Thermal Solutions

Factor Testing

- Patty Temperature Logs
- Room Environment
- Oven Profile
- Measurement Technique Comparison

Patty Temperature Logs

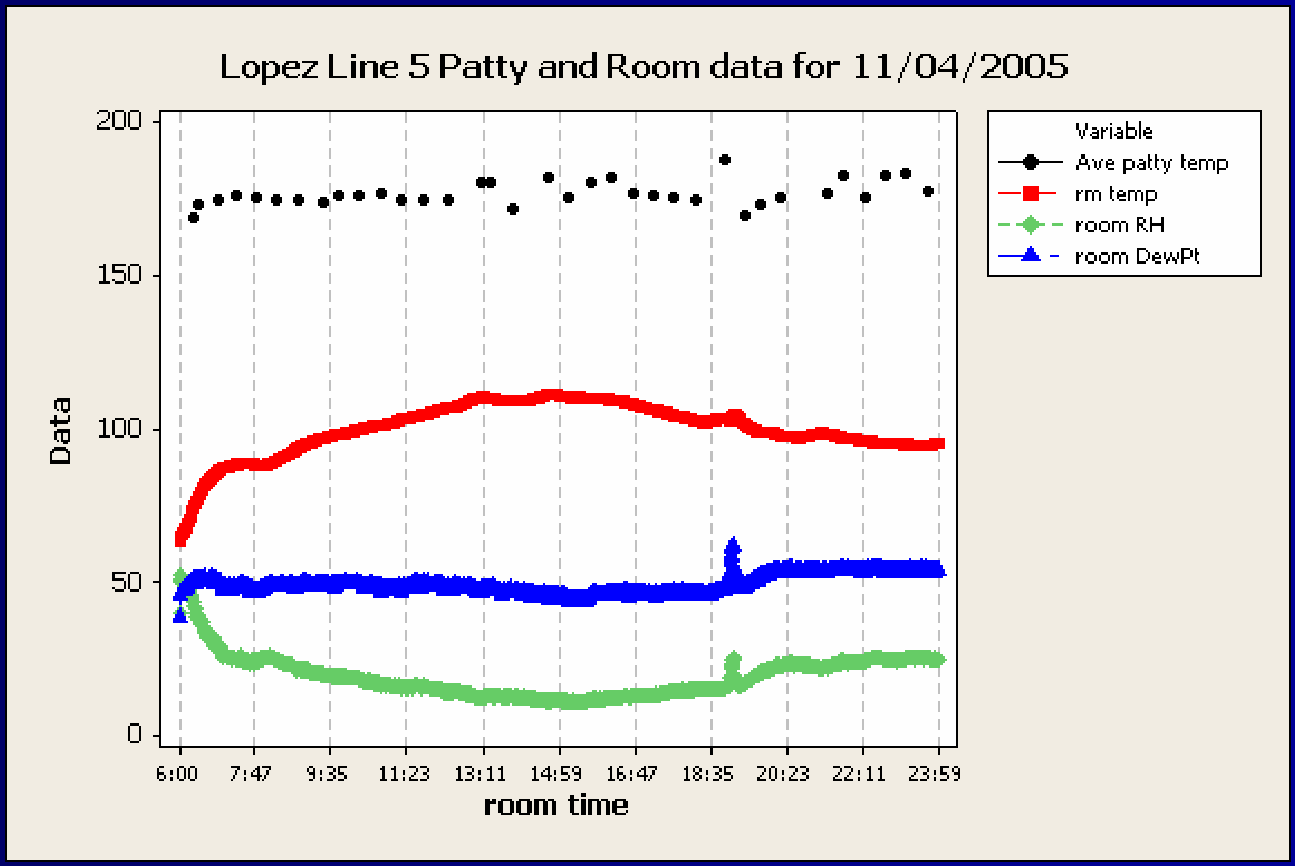


Thermal Solutions

Environment

- Onset Hobo® Data Logger
- Recorded 7 days of Temperature and RH

Environment



Thermal Solutions

Oven Profile

- Definition
- Pace Scientific XR440 Data Logger
- Designed custom apparatus

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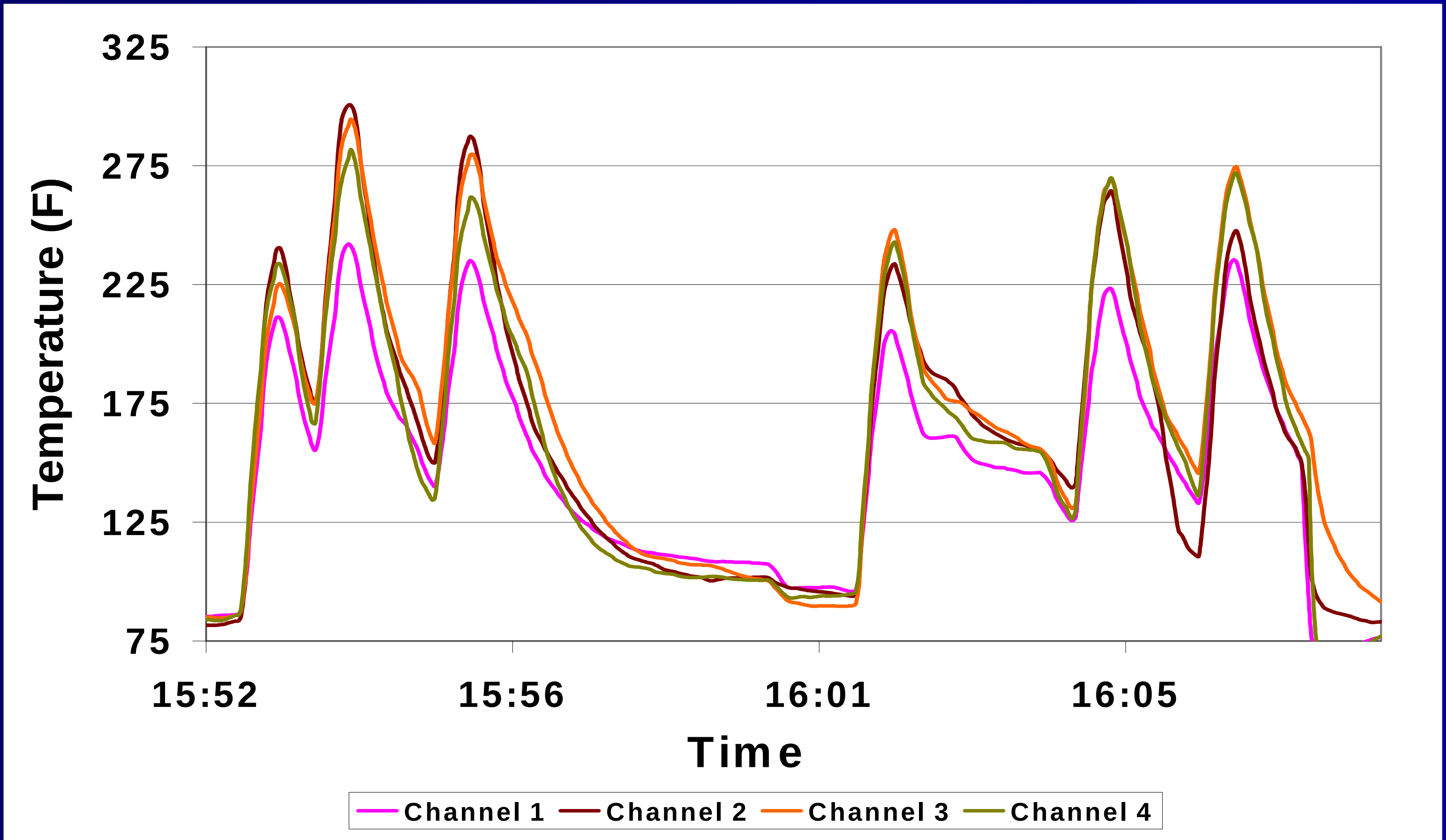
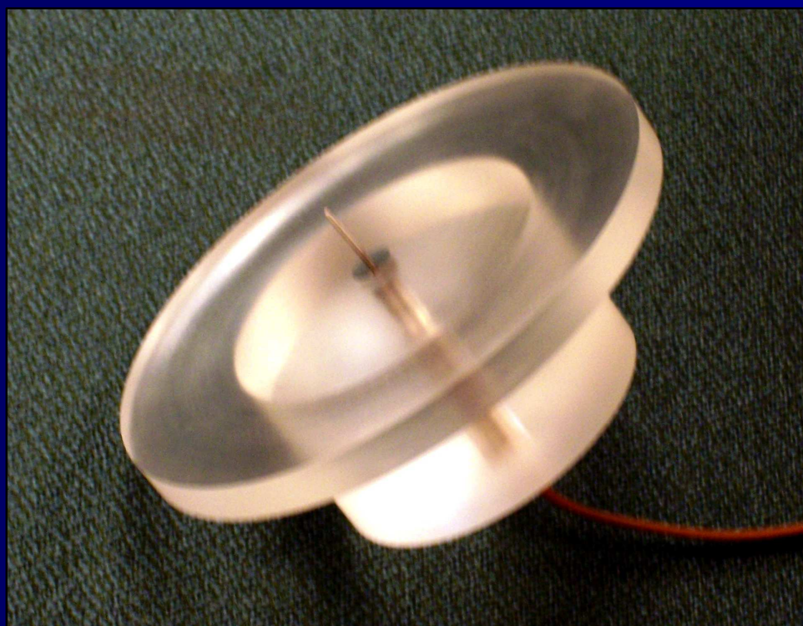
Oven Profile



Thermal Solutions

Technique Comparison

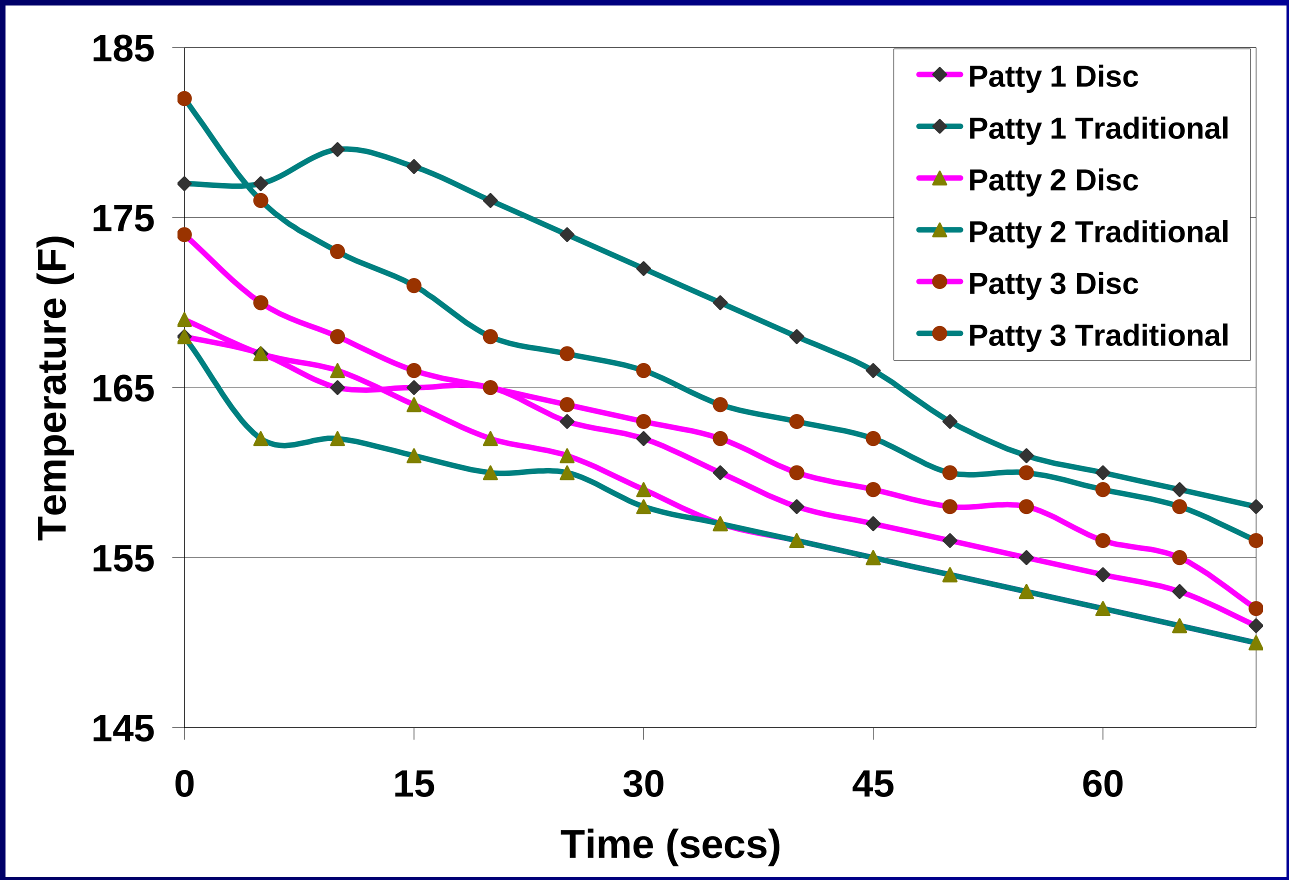


Disc Probe

Side Probe

Thermal Solutions

Technique Comparison



Conclusions

- Eliminated Factors
  - Environment
  - Product
- Remaining Factors
  - Temperature Measurement
  - Feeder / Conveyor Speed
  - Oven System

Future Work

- Temperature Measurement
  - Find patty temperature profile
  - Implement new device
- Profile entire oven
  - Redesign data logger
- Examine feeder/conveyor effects

Thank You!

Lopez Foods, Inc

Dr. Kevin Nanke
Corporate QA Director

Ms. Lori Leininger
QA Team Leader

BAE Department

Dr. Paul Weckler
Senior Design Professor

Dr. Timothy Bowser
Food Processing Engineer

Mr. Douglas Enns
Senior Applications Engineer

Mr. Wayne Kiner
BAE Lab Manager

Thermal Solutions

Any Questions?

Thermal Solutions