FACTORS AFFECTING HEATING OF CALZONES IN MICROWAVES

by

LORRI DENISE CULLEN

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Major Professor
Dr. Fadi Aramouni

Abstract

Determining the optimum cooking instructions for microwavable not-ready-to-eat foods requires an understanding of the factors that affect heating of foods in microwaves. Factors are often studied without consideration of interactions. Consumer-driven factors appear to be the least-studied. Microwave appliance, heat time, flip step, and plate material were studied to determine their effect on final temperature of a frozen hand-held calzone sandwich after heating. Initial studies to ensure wattage stability during testing and a study to narrow down the plates to be tested were also executed. In the central experiment, a calzone was heated on a microwavable plate for one minute, then flipped or not flipped and heated again for the remaining time in each of four microwave ovens. The microwave ovens differed in age and manufacturer, but were of similar stated wattage. Probes were attached to a data logger and temperatures were recorded every 5 seconds for 2 minutes post-heating to attain the average maximum temperature and lowest maximum temperature for each run. The data was evaluated by analysis of variance and significant differences were compared using Tukey means. All factors had significant effects on average maximum temperature and lowest maximum temperature with the exception of the flip step ($p < .05$). Plate type was the most critical factor. Calzones heated on paper plates were significantly hotter than those on stoneware plates ($p < .05$). Significant differences were also observed among microwaves and heat times ($p < .05$). An interaction between microwave and plate type indicated the effect of plate type was not consistent across all microwaves ($p < .05$). Although flip step, as tested, was not a significant factor, a follow-up experiment to de-couple the effect of the physical flipping of the calzone and the stopping of the microwave during the heating process indicated that the stopping of the microwave was more critical to heating than the actual flip step. A follow-up study of plate type, microwave and heat time in higher-wattage microwaves showed that microwave appliance and heat time again had significant effects on temperature ($p < .05$), however; plate type was not a significant factor in the higher-wattage microwaves. The effect of plate type was dependent on the exact microwave used. Various plate types and multiple microwaves in each wattage range should be used for development of microwavable frozen calzones because wattage alone cannot predict performance and because of the interaction between microwave and plate type.

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Introduction

Each year in the U.S. an estimated 76 million cases of foodborne illness are recorded by the Centers for Disease Control and Prevention (CDC) (CDC 2005). Microwavable foods that are considered Not-Ready-To-Eat (NRTE) have been implicated in several recent outbreaks (Williams 2008). In many cases, under-cooking or consumer deviation from the cooking instructions was thought to have led to some of the illnesses (CDC 2008). In 2006, the U.S. Department of Agriculture (USDA) issued requirements for manufacturers to validate that NRTE cooking instructions, if followed by the consumer, would achieve a killstep and render the food safe for consumption. Most consumers have several appliances to choose from when cooking NRTE foods, including microwave ovens. Uneven heating in microwave ovens make it the most challenging cooking method to validate. Food formulation, physical form of the food, and appliance factors all contribute to uneven cooking and many of these factors are well-documented in research. The effects of consumer-driven factors are less reported but their effects need to be understood. These consumer-driven factors vary considerably for each food product but may include the following; choice of plate type to heat the food on, heating time, and choice to stir, flip, or cover as directed.

This research aims to understand the impact of several consumer-driven factors on heating of a frozen NRTE calzone in the microwave and is presented in five parts. There were two initial tests conducted. The first study was conducted to ensure that test runs would be executed under stable wattage conditions and is described in Chapter 2. The second study was conducted to narrow down the plate types chosen for testing and is described in Chapter 3. The main test described in Chapter 4 examined the effect of plate type, flip method, and heat time in a set of lower-wattage microwaves. The results from this study led to a follow-up study described in Chapter 5 to de-couple the effects of flip step and stopping of the microwave during heating to perform the flip step. Chapter 6 describes the secondary study of plate material and heat time in a set of higher-wattage microwave ovens. Previous research has been generally limited to one microwave; however, this research tested the effect of factors across a wide range of microwaves and wattages as would be required to validate consumer cooking instructions. It was hypothesized that while many factors affect heating rate, most are minimal in comparison to the differences between microwaves even microwaves of similar wattage. Testing all factors that may affect heating for a validation program is time-consuming. An understanding of the relative importance of several factors allows for the creation of optimized validation testing protocol. This information is valuable to anyone engaged in testing and validating cooking instructions for NRTE microwavable foods.

CHAPTER 1 - Literature Review

Risks Associated with Not-Ready-To-Eat Products

The number of reported foodborne disease outbreaks involving *Salmonella and Escherichia coli* has increased over the past 10 years. Many of these outbreaks involved NRTE foods that consumers prepared in their microwave.

Each year 76 million cases of foodborne illness are estimated by the CDC. One in four Americans gets a foodborne illness every year, one in 1,000 is hospitalized and an estimated 5,000 deaths occur (CDC 2005). The Economic Research Service of the USDA estimates the human illness cost from five bacterial foodborne pathogens alone approached $6.9 billion in 2000 and the total cost estimate for *Salmonella* alone reached over 2 billion dollars in 2008 (ERS 2009). At the International Association for Food Protection (IAFP) Timely Topics Symposium in 2008, Ian Williams of the CDC reported that common themes among recent outbreaks included:

frozen, microwaveable NRTE processed foods were involved;
consumer confusion existed over the raw nature of the product;
consumers did not follow package directions.

Previous incidences of *Salmonella* outbreaks in raw chicken nuggets and strips in Australia in 1998 and again in Canada in 2003 involved undercooked microwaveable foods (CDC 2008).

Quick identification of an outbreak and rapid identification of the source is extremely important. The CDC supports a team of nationwide epidemiologists from local and state health departments, FDA, and USDA. In conjunction with PulseNet, a national molecular subtyping network for foodborne disease surveillance, they are able to investigate reported illnesses across multiple states and link together these incidents by DNA analysis of the disease-causing organism. Interviews with affected people and with a control group close the loop to identify the exact food source in order to stop the spread and alert the public.

A 2007 outbreak of *Salmonella (Salmonella* serotype I 4,[5], 12:i:-) as reported in the Morbidity and Mortality Weekly Report, Nov. 28th, 2008 illustrates this process. This particular variant was rarely recognized before the 1990's and the epidemiology is not well understood.

The 2007 outbreak was first flagged by PulseNet in June, 2007. The CDC created a food diary questionnaire to isolate the potential source in August. On Oct. 3rd, a multi-state case-control study was initiated. This study initially didn't include a question about pot pie consumption but when the Minnesota Department of Health (MDH) reported that five affected people they interviewed has consumed pot pies, this question was added to the case-control multi-state study and very quickly pot pies were confirmed as the source (71% of cases reported consuming pot pies, while 0% of controls did.) On Oct. 9th, FSIS posted a consumer advisory and on Oct. 11th, there was a voluntary recall of the pot pies by the manufacturer. The directions for this product instructed the consumer to place the pot pie on a microwave-safe plate and microwave on high for 4 minutes if using a medium or high watt microwave and 6 minutes if using a low watt microwave. The consumer was instructed to let the pot pie stand for 3 minutes after heating. The package did not give instructions for heating more than one pot pie at a time. Information gathered during the interviews with infected people revealed that 77% prepared the pot pie in the microwave, 68% did not let the pot pie stand the full recommended time after heating and 19% prepared more than one pot pie at a time (CDC 2008). Clearly the cooking instructions were not followed or were inadequate to secure a safe product.

On October 3rd, 2008, MDH reported the 6th outbreak in the past 11 years related to *Salmonella* found in NRTE stuffed chicken breasts. In a report released October 3rd, 2008, the MDH urged the public to not use the microwave for preparation of the frozen chicken breasts due to risk associated with undercooking (MDH 2008). The products involved were NRTE but appeared to be fully-cooked since they were breaded and flash-fried for a crispy and browned outer texture. Because the products did not look or smell raw, the consumer may have assumed that they did not need to fully cook the products (MacDougal 2004).

Food prepared in the microwave presents unique challenges to consumers with regards to determining when their food is properly cooked. For some products, lack of transformational change such as color development or texture changes during the microwaving process inhibit a consumer's ability to determine doneness. For other products, the visual appearance is confusing. Sheryl Cates, RTI International, reported that in studies conducted by RTI, consumers reported confusion over whether certain food items such as frozen, breaded chicken nuggets or frozen sandwiches needed to be cooked for safety. They are well aware that certain items such as raw meats require cooking before safely consuming, but consumers rely on color, texture, experience, and cooking time to determine doneness instead of temperature. The USDA has published a Fact Sheet entitled, “Meat Preparation: Color of Cooked Ground Beef as it Relates to Doneness.” In the fact sheet, they reference a 1996 Kansas State University meat sciences study which found:

> “that a sufficient number of ground beef patties were turning brown well before they reached 160 °F to make color an unreliable indicator of doneness. A consumer who believes a brown color always means a safe hamburger is taking a chance on foodborne illness.”

The FDA Food Safety Survey (1998-2006) results indicate that only 12% of consumers use a thermometer when grilling hamburgers. Consumers are even less likely to use thermometers for frozen meals than when cooking raw meats due to inconvenience and lack of awareness of the need to fully cook these items (Cates 2008).

Observational studies of adults and adolescents in a kitchen preparing NRTE frozen chicken products, conducted by DeDonder and others (2009) revealed that only 7% of participants followed all of the cooking instructions. Only 12% used a thermometer to measure end-point temperature and a full 56% made no attempt to determine doneness after preparing the food. Consumer education is needed about the proper way to identify and cook NRTE foods, especially in the microwave.

What is a Not-Ready-To-Eat Product?

The Food Safety and Inspection Service (FSIS) of the USDA is the unit “…responsible for ensuring that the nation's commercial supply of meat, poultry, and egg products is safe, wholesome, and correctly labeled and packaged. This includes packaged foods that contain 2-3% meat (FSIS, 2009).” These foods fall into two classifications, Ready-to-Eat (RTE), and NRTE. These are critical classifications with regards to food safety and different regulations apply to the manufacture of each class of food. The FSIS defines the NRTE category as “…“raw” for purposes of current FSIS focus regarding sanitary conditions and presence of pathogens” and the RTE category as “…safe to consume without further lethality treatment.” “Ready-to-Eat Food” is defined by the FDA in the 2009 Food Code as food “in a form that is edible without additional preparation to achieve food safety…” Essentially, no cooking of the food is required by the consumer for the purposes of food safety; however, cooking or heating may be desirable for palatability of the food. At the IAFP Timely Topics Symposium in 2008, Jenny Scott, formerly of the Grocery Manufacturers Association (GMA), defined the NRTE category as those foods which "Contain at least one ingredient for which the elimination of vegetative pathogens such as *Listeria monocytogenes* and *Salmonella* cannot be assured by the manufacturer" and for which the "consumer must cook the food prior to consuming." While the definitions may appear simple and concrete, it is not clear to consumers.

There are specific lethality standards in FSIS regulations for RTE foods; however NRTE foods are not covered by these regulations. The Hazard Analysis and Critical Control Points plans differ greatly for these two categories. Production of RTE foods require rigorous testing of food contact surfaces, temperature control and testing of finished goods to ensure that the foods are not contaminated with organisms which may result in foodborne illness if consumed by the public. The regulations governing NRTE foods do not require plant-level testing of finished products. Instead the manufacturer is required to include safe handling instructions on all raw meat and poultry. As of late 2006, for NRTE packaged foods, the cooking instructions must be validated by the manufacturer to ensure that a consumer will safely cook the food to temperatures of lethality when following the cooking instructions (FSIS 2006). Manufacturers need to know their food system thoroughly to understand what cooking conditions will render the food safe to eat if it is contaminated, and the most challenging cooking condition is the microwave.

Microwaves and Heating of Foods

Today, the U.S. household penetration of microwaves has reached 96% (NPD Group 2008). A microwave heats food by use of a magnetron which supplies an alternating microwave electric field of energy. A waveguide is used to direct the microwave energy into the cavity of the microwave and may first pass through a stirrer which helps distribute the waves more evenly. A stirrer is not used when the microwave cavity contains a turntable which is designed to function in the same way. The primary mechanism by which foods are heated in a microwave is via the microwave interaction with water molecules which are polar. When the alternating electric field is applied, the water molecules attempt to align themselves with the field and when it reverses, they also attempt to reverse. Collisions occur which create thermal energy. Water molecules in the form of ice are physically bound within the crystalline structure and cannot react as well to the alternating field. This has implications when developing frozen foods for the microwave. Secondly, this alternating field will exert an effect on any charged particle within and the effect causes acceleration and agitation of particles which imparts kinetic energy and increases the particle's temperature. Particles thus affected will transfer energy to neighboring particles and so on, and in this fashion microwave energy is also converted to heat by the physical acceleration and agitation of particles (Buffler 1993).   While much is known about how microwave ovens work, predictions of heating rates and heating uniformity are still highly complicated.

The most critical difference between microwave cooking and conventional oven cooking is non-uniform heating in the microwave. Uneven heating can be explained as a blend of resonant and absorption mechanisms. Microwave energy entering a food is partially absorbed but also reflected on opposing surfaces. This gives rise to interference and focusing (Keefer 1992).   It is often difficult to know with any certainty that a given measured temperature is indicative of the whole, or even that the center temperature is the coldest (O'Meara and Reilly 1986; Ryynanen and Ohlsson1996; Goksoy 1999).   With conventional heating, the product is heated by conduction or convection, the heat surrounds the food and moves slowly towards the center of the food. The surrounding air is much hotter than the food and heat penetrates the food from the outside in. Therefore, the center or thickest part of the food item is the coldest. This is not universally or repeatedly true in microwave heating. In addition, typical heating times in a microwave are short and therefore there is less room for error. These differences and others to be addressed require that special attention be given to development of cooking instructions for NRTE foods in the microwave.

Factors Known to Affect Heating in Microwaves

The many factors that influence heating in the microwave can be categorized into five types: food formulation, physical form of the food material, appliance, packaging, and consumer input.

Food Formulation Influences

While the formulation and the physical form of the food material is usually finalized when it comes time to validate the cooking instructions, a brief mention of how these factors can affect the heating of microwaved foods is warranted. The most commonly reported and studied formulation manipulations employed to manage heating involve altering the dielectric properties (dielectric constant ε', and loss factor ε'') of the food material. These properties influence how microwave energy is deposited into the food. The dielectric constant, ε', is a measure of how the food reacts to the electric field. If the food material is very polar and reacts strongly to an electrical field, it will have a high dielectric constant. The loss factor, ε'', is a measure of the microwave absorptivity of the food and is heavily influenced by the amount of dissolved ions in the system. The more conductive a food is, the higher the loss factor and the less the microwave energy can penetrate into the food. Together, the dielectric constant and the loss factor strongly influence the penetration depth of the microwave energy field, and thus heating. These factors are influenced by temperature and become critical when examining frozen foods. The dielectric constant and loss factor are much lower for ice (ε'= 3.2, ε'' = .003) than for water (ε'= 77.4, ε'' = .9.2) (Buffler 1993). Water molecules when frozen are "locked in place" and incapable of rotating with the electric field. A phenomenon known as "runaway heating" occurs where any amount of thawed material present will begin to heat far more rapidly than any surrounding frozen material which exacerbates the uneven heating.

In most food systems, significant adjustments to the dielectric constant or loss factor put the food outside the bounds of acceptability by the consumer (Ryynänen and Ohlsson 1996; Ryynänen and others 2004). For any given food it may actually be more beneficial to adjust physical factors that affect how a microwaved food continues to heat once the energy has been deposited, than to manipulate the dielectric constants. These physical factors include thermal conductivity, heat capacity, density, and volume (Buffler 1993).

Physical Form of Food Influences

Once the heat has been introduced into the food, physical factors such as thermal conductivity, heat capacity, density, and volume will influence how the heat distributes throughout via conduction much like in conventional heating methods. The physical shape or form of food materials can also greatly affect heating in the microwave. Ryynänen and others (2004) found that modifications to the geometry of a hamburger patty and bun were more successful at increasing heating uniformity than changes to the dielectric factors. Rectangular or irregular shaped foods often heat less uniformly than foods in a spherical or round shape due to excess edge and corner heating. Excess heating on edges or corners occurs when a slab of food or food in a tray has sharp corners or edges. The edges and corners of the food are hit from more than one direction by the microwave and thus heat more quickly than the food in the middle. Rounded corners and round containers are often used to mitigate this problem. For products that are spherical or cylindrical, there is a special phenomenon called focusing where the refracted rays in the interior of the material can collide due to the multiple angles at which they can enter the surface. This can lead to faster heating in the interior and is responsible for the "bumping" that occurs in soups and stews heated in cylindrical containers (Buffler 1993). The surface area and the load volume relative to microwave cavity size can affect uniformity of heating as well (Anantheswaran and Ramaswarmy 2001).

During heating or thawing, a "salty shield" can develop at the surface of the food being heated. As the outer surface of the food material heats and moisture is lost, the dielectric property of the surface changes and the microwaves are less able to penetrate into the product. This situation is exacerbated when heating frozen food systems. A plot of thawing time versus percent power will not yield a linear relationship. As the power level goes up, the reduction of thawing time actually decreases because of the "salty shield" development (Chamchong and Datta1999). The observation of this phenomenon led some researchers to recommend manufacturers not include salt in their formulations for microwave products to reduce the potential for under-heated microwaved foods (Dealler, 1990). Even when the food formulation and physical conditions are set, there can be a high amount of variability introduced by the appliance.

Microwave Appliance Influences

Design elements of the microwave appliance can affect the heating of foods. Wattage output, cavity size and shape, and the wall material are all important (Buffler 1993). A single microwave can also vary in the amount of wattage applied to food products within based upon several factors such as 1) variation in the supply voltage applied to the circuit which affects wattage output, 2) effective wattage reduction which is observed with increased operation, and 3) effective wattage reduction which occurs as the appliance ages (Hooper 2008). It is well documented that rotating turntables contribute to greater uniformity (Oliveira and Franca 2002). Geedipalli and others (2007) found a 40% increase in uniformity of temperatures when employing the use of a turntable. The effect of pulsed microwave heating of the type that occurs when operating the microwave at lower than 100% power is less certain. Some researchers have found an increase in heating uniformity when using a heat/hold cycle as is accomplished with a "defrost" setting on a microwave (Fakhouri and Ramaswamy 1993; Gunasekaran and Yang 2007) while others have reported no advantage to using power levels below 100% (Chamchong and Datta 1999; Oliveira and Franca 2002).

The output power of a microwave slowly decreases during continuous use (Swain and others 2006). When the magnets in the magnetron heat up, the magnetic field they produce diminishes. Research has shown this to drop to be as great as 20% and it usually occurs during the first five to 10 minutes of use (Buffler 1993). Swain and others (2006) also reported a 17.3% reduction in output power after 30 minutes of continuous use. Swain and others (2008) further illustrated how this measureable drop in wattage output led to a significantly lower temperature for foods heated in 75% (12 of 16) of microwaves that had been in continuous use for 15 minutes. Although not the focus of the research, the resulting drop in wattage was also measured to be stable after 10 to 20 minutes of continuous use. This has implications for both consumers and for the product developer as they test products in the lab.

Packaging Influences

Microwave packaging elements can be successfully utilized to control or manage heating of foods. By incorporating materials with different reflection, absorption and transmission characteristics, the effect of microwave energy on the food inside the package can be reduced or enhanced throughout the entirety or only portions of the package. The very first patents for active microwave packaging were granted in the 1950s and work continues today to increase the function of packaging to allow for browning, crisping and more even heating (Anathaneswaran and Ramaswamy 2001).

Consumer Influences

Even after all of the aforementioned factors are taken into account, considerable variability can be introduced by the consumer who ultimately cooks the food in the microwave. Consumers can deviate from every step of the cooking instructions and thus influence heating. A 2007 Consumer Survey Report issued by the International Microwave Power Institute (IMPI) indicated that while 85% claim to follow the cooking directions on the package, 32% of consumers stated that if the package instructions indicate you should use less than 100% power, they will ignore that or will heat on 100% power and reduce the time instead. When asked if they rotate or stir as indicated in the directions, 30% of consumers ignore or only partially follow those directions. Only 2% of consumers check the temperature of the food to determine if it is done and a full 30% will taste it to determine if it is done. The percent of consumers that do not know the wattage of their microwave oven was 40%. Placement in oven, product temperature, plate type, flipping and/or stirring, heat time, stand time, and covering/not covering are all influential factors that are ultimately controlled by the consumer and can have critical influences on the final temperature achieved during heating.

Covering foods while heating can eliminate the evaporative cooling that occurs when foods are microwaved. Since the air surrounding the food is not hot and the microwaves penetrate the surface, as the food heats, the surface cools off. Covering the food while heating will trap the heat in and the surface temperature of the food will be higher (Buffler 1993).

Certain foods can be stirred and doing so will reduce the non-uniformity of temperature in the food. In addition, stand time after heating will allow the food to equilibrate and may be necessary to reach lethality temperatures (Datta and Davidson 2001).

It is important that developers consider all of the above factors when determining whether the cooking instructions will achieve a killstep for consumers when heating their NRTE foods in the microwave. In order to satisfy the USDA requirements, a validation program should be established to gain a thorough understanding of all of these factors.

Validation Programs

The FSIS issued a notice in late 2006 regarding NRTE products available for retail sale. Included in the notice was a charge to companies to validate the primary cooking instructions provided to the consumer. Interest in these products intensified during the summer of 2007 when NRTE products such as the pot pies mentioned earlier were implicated in foodborne illness outbreaks. This charge to validate the cooking instructions means that the manufacturer must execute testing and produce documentation of that test data that the consumer cooking instructions, when followed, will achieve a killstep (GMA 2008). A killstep is defined as a process (typically a set temperature or a combination of temperature and time) which reduces the microbial load to safe levels (GMA 2008). The manufacturer must determine the target lethality temperature or time/temperature combination. Many factors contribute to the determination of the target lethality such as whether the food contains raw or cooked ingredients, and the anticipated microbial load of the incoming raw materials. In general, a target of 160ºF is considered safe for all foods other than those with raw poultry which must reach 165ºF. The FSIS states:

> "The cooking requirements recommended to consumers should at least achieve the same level of pathogen reduction required of food processors (i.e., a 7-log reduction of *Salmonella*, the level of lethality required in 9 CFR 318.150(a)(1), should be the target level of reduction). A process sufficient to control *Salmonella* will also control *Campylobacter*, another pathogen of concern in poultry (e.g., a 7-log reduction process for *Salmonella* would achieve a greater than 50-log reduction of *Campylobacter*)" (2006).

Currently no documentation needs to be submitted; however, a USDA inspector may ask for this data and it must be provided upon request (National Advisory Committee 2006).

A working group of industry professionals formed in 2007 and led by the Grocery Manufacturers of America (GMA) created guidelines for manufacturers for validating cooking instructions for NRTE products to ensure that "…NRTE products cooked according to the instructions on the label are safe to consume." The main focus of the guidelines is to encourage manufacturers to use temperature verification and/or microbial challenge studies to ensure that the cooking instructions meet a killstep. Recommendations also address the need to validate all instructions for all appliances that are printed on the package. Specific to microwave ovens, is the need to determine the wattage of the ovens being used for validation. It is recommended that the output wattage of microwave ovens be measured using the International Electrotechnical Commission (IEC) method 60705 ed. 3.2, 2006 – "Household microwave ovens - Methods for measuring performance".

The USDA published information for manufacturers highlighting the need to take into consideration all the aforementioned factors when validating cooking instructions or anticipate the need to explain why these factors are not relevant to individual products or groups of products (HHS 2007). Validation of cooking instructions for NRTE microwave foods is further complicated by the collection of temperature data which can be challenging.

Temperature Collection

Collection of temperature data during heating in the microwave can be accomplished via fiber optic probes or by use of infrared cameras. Drawbacks to the fiber optic probes include the need to modify the microwave cavity by creating a hole in the wall of the microwave through which the fiber optic probes can be introduced into the cavity. For frozen products, the food material must also have holes pre-drilled into the surface in order to introduce the probes into the interior of the food material during heating. Both of these modifications limit the usefulness of fiber optic probes since the number of microwaves you can modify and equip with probes may be limited by cost and the holes pre-drilled into the food item can introduce variation and may affect heating. In addition, the probes are small and measure only very localized temperature. It is impossible to determine where the hot spots or cold spots may occur as you might be able to detect with an infrared camera (Mullin and Bows 1993). Infrared cameras provide a thorough measurement of the temperatures across the entire surface of a food material and therefore are very useful for understanding heating uniformity and can be analyzed statistically. The infrared camera is limited to surface temperature readings; however, and not appropriate or capable of validating internal temperatures.

The use of magnetic resonance imaging (MRI) has been recently demonstrated as a non-invasive, three-dimensional approach to temperature measurement, though the MRI equipment is not operational in a metal cavity microwave. MRI can be used as a non-invasive temperature measurement technique post-heating in a microwave. Far more data can be gathered on a single food item than when using traditional thermocouples. Gao Amin and others (2007) demonstrated this with baby food heated in glass jars. The maximum temperature recorded via thermocouples post-heating and after stirring the baby food was significantly lower than the maximum temperatures recorded using MRI technique. At this time, MRI equipment is cost-prohibitive for most operations.

Bimetal thermocouples can be used post-heating to measure temperatures and are the most commonly used method because of cost and ease of use. A specialized apparatus can be built to secure multiple thermocouples which can be positioned on the food item after heating to penetrate at differing depths and thus an attempt can be made to measure the internal temperatures. Studies can be done with food systems to determine where hot and cold spots are likely to occur and thermocouples can be preferentially positioned in those locations.

Because it is not easy to measure the entirety of the sample and ensure that all points have reached a killstep, the GMA encourages manufacturers to use also microbial challenge studies for any food samples where the cold and hot spots are not possible to detect via temperature probes (GMA 2008).

Lethality determination

Research has shown that lethality of pathogens does occur when cooking in a microwave (Davidson 2008) and that lethality occurs through the standard time/temperature heating mechanism that a regular oven provides (Heddleson 1994; Anatheswaran and Ramaswamy 2001). The microbial factors that affect inactivation in the microwave are the same as for any other heat process and include genus, species, strain, whether the organism is a vegetative cell or spore, and whether the organism is under stress. Extrinsic factors such as time and temperature and intrinsic factors such as the mass, density and geometry of the food are also important (Bibek 2004).

Heat Resistance of Pathogens of Concern

For NRTE foods designed for the microwave, pathogens of concern are *Salmonella* strains, *Listeria monocytogenes*, and *Escherichia coli (O157:H7),* all of which have been recently implicated in outbreaks (National Advisory Committee 2006). The manufacturer of a NRTE food works diligently to ensure that ingredients and finished foods are not contaminated with pathogens; however, it is very challenging to detect these organisms when present at very low numbers. If they are present, they may not be detected by the manufacturer due to the lack of finished product testing performed or required on NRTE products as would be required for RTE products. The cooking process performed by the consumer when following the cooking instructions is the only defense against foodborne illness if a NRTE product is unknowingly sold in a contaminated form.

A proper cooking process applies a heat treatment to the food which will render the food safe to consume, even if contaminated. What constitutes a proper cooking process differs depending on the food item and the microorganism of concern. Influential factors related to the food include the composition, a_w, pH, antimicrobial agents, and physical form of the food (Bibek 2004). Influential microbial factors which affect the lethality of the heat treatment include inherent resistance of the species and strains, the stage of growth, any previous exposure to heat and the initial load in the food sample (FASS 2001). Lethality time temperature combinations for microorganisms in food vary with spores having the most resistance to heat as shown in Table 1-1(Bibek 2004).

Table 1-1 – General lethality conditions for common microorganisms.

Microorganism	**Time/Temperature for lethality**
Cells of mold, yeast, viruses, and many bacteria (except thermophilic and thermoduric)	10 minutes at 65ºC
Thermoduric and thermophilic bacteria important to food	5 to 10 minutes at 75ºC to 80ºC
Yeast and most mold spores	A few minutes at 65ºC to 70ºC (molds of some spores can survive for 4-5 hours at 90ºC)
Bacterial spores	30 minutes at 100ºC destroys many (though some will survive boiling for 24 hours)
All Spores	15 minutes at 121ºC (sterilization temperature)

Determining an adequate heating time for a specific food system involves identifying the specific organism of concern and then obtaining the D-value and z-value for that organism in that food system from literature, or conducting studies to measure them directly. The D-value is the time in minutes required to reduce the microbial load (cells or spores) in a food exposed to a specific temperature by 1 log (or 90%).

The D value can be determined by calculating:

$$D_T = t/\log_{10}x - \log_{10}y$$

where x and y represent the microbial load before and after exposure at "t" time to "T" temperature. The Thermal Death Time (TDT) is an expression of the time needed to completely destroy a specific number of cells at a specified temperature. The slope of this curve is the Z value and represents the temperature needed to reduce the TDT by a factor of 10. These calculations are most commonly used to determine processing times during manufacturing (Bibek 2004). These calculations are not commonly applied to the cooking process performed by consumers. However, in order to have an accurate picture of whether the cooking instructions on a package of NRTE food will provide adequate lethality if there is contamination, these concepts can be applied to the cooking instructions to help determine if the directions will provide a safe product (GMA 2008).

The American Meat Institute Foundation (AMIF) has provided guidance to manufacturers regarding lethality calculations. They provide a spreadsheet on their website (www.amif.org) entitled "Process Lethality Determination Spreadsheet" which requires the user to enter the D and z-values specific to their product along with temperatures obtained from a cook process and the log reduction for a given organism is calculated. This spreadsheet can be used to calculate lethality for a consumer cook step.

A summary of the key factors to consider when developing a validation program and verifying that a killstep has occurred when following the cooking instructions is presented in Table 1-2.

Table 1-2 – Summary of factors to consider when validating cooking instructions for NRTE microwave foods.

Factor	How it affects heating
Food Formulation	dielectric constants of the food which are determined by solutes and affected by temperature will affect how much microwave energy is absorbed by the food material
Physical Form	thermal conductivity, heat capacity, density, volume, geometry may affect both how much is absorbed and how well the energy is distributed once it gets inside
Appliance	Wattage output, cavity design, turntable, supply voltage, heat/hold cycling, continuous-use power reduction, and age of appliance will all affect how much wattage is produced
Packaging	Packaging materials and geometries can affect how much microwave energy is absorbed by the food inside
Consumer	Placement in oven, product temperature, heat time, stirring, covering, stand time, can all affect heating

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CHAPTER 2 - Preliminary Study - Wattage Stabilization

Abstract

Ensuring a stable wattage during testing is critical when conducting microwave testing with food products. Because wattage output varies during the first 5-10 minutes of continuous use, research is typically conducted after a pre-heat step or in microwaves that have not been in use for a minimum of five h. The goal of this preliminary study was to establish that the wattage output in eight different microwave ovens was stable after a 10 minute pre-heat step. This would allow for back-to-back testing in a single microwave in a stable wattage period. The three conditions studied were initial wattage of microwave, wattage after a 10 minute pre-heat, and wattage after a 10 minute pre-heat step plus three cycles of heating frozen calzone products. Eight microwaves from various manufacturers and of various ages ranging in stated wattage from 700 watts to 1200 watts were tested. An IEC wattage output test was performed in each microwave prior to any pre-heating to establish the initial wattage. The microwave was "pre-heated" by heating 1,000 g of water for ten minutes on high (100% power). An IEC test was then conducted. Following this second IEC test, a series of three calzones were heated in succession. A final IEC 60705 wattage test was performed to ensure that no change in the output wattage had occurred. This entire process was duplicated for each microwave. For the eight microwaves tested, an average decrease in wattage output of 15% was observed after pre-heating. A period of stability with wattage change of less than 5% existed between the pre-heat steps and after three calzones and two IEC tests were completed. This pre-heat step which simulates continuous use created a steady state condition during which multiple runs could be executed back-to-back in the same microwave.

Introduction

The output power of a microwave slowly decreases during continuous use (Swain and others 2006). Research has shown this to be a drop as great as 20% and it usually occurs during the first five to ten minutes of use (Buffler 1993). This must be taken into consideration when establishing test conditions for validation of cooking instructions. The 2008 GMA Guidelines for Validation recommend that manufacturers either utilize a rest period to allow the magnetron to cool back to room temperature between test runs in a single microwave, or to "pre-heat" the microwave for a minimum of ten minutes after which a steady state can be achieved and multiple runs can be executed back to back in a single microwave. It is recommended that the wattage variation during this steady state not exceed 10%.

In addition to creating a steady-state, testing in microwaves that have been pre-heated represents a real situation that consumers face when using microwaves in the office, cafeteria, or convenience store. Although it is impossible to measure how often a consumer heats a food item in a microwave that has not been in use for more than 5 hours versus a microwave that has been in continuous use, the number of people with access to a microwave at work is 72%, and 53% of people use it at least once a week to prepare a meal (IMPI 2008).

This goal of this preliminary study was to establish that the wattage output in 8 microwave ovens stabilized after a 10 minute pre-heat step which was used to simulate continuous use.

Materials and Methods

The three conditions studied were initial wattage, wattage after 10 minute pre-heat, and wattage after 10minutepre-heat plus three cycles of heating frozen calzone products. Eight microwaves from various manufacturers and of various ages ranging in stated wattage from 700 watts to 1200 watts were tested.

To measure initial wattage, an IEC wattage output test was performed prior to any pre-heating using a microwave that had not been in use for a minimum of five hours. To create the "pre-heat" condition, a 1.42 L mixing bowl (Anchor Hocking ®, Lancaster, OH) filled with 1,000 g 4 °C spring water (Chippewa® Spring Water, Premium Waters, Inc. Minneapolis, Min.) was heated on HIGH (100% power) for 10 m. This bowl of water was removed. The turntable was removed and cooled with room temperature tap water and the sides of the microwave were wiped down with a wet room temperature cloth. Within 1 m, an IEC 60705 wattage test was performed to measure output wattage. Following this second IEC test, a series of 3 calzones (104.1 g, held at -17.8 °C, provided by General Mills, Inc. Golden Valley, Min., USA) were heated in succession. Each calzone was heated for 1 minute on HIGH. The microwave was stopped, the door opened, the calzone flipped over, and the door closed. The calzone was then heated for another 1 minute on HIGH. Following the 3 calzone test runs, the turntable was again removed and cooled to room temperature and the sides of the microwave were wiped down again. Within 1 minute, a final IEC 60705 wattage test was performed to ensure that no change in the output wattage occurred. This process was duplicated for each microwave. Power to the microwave was controlled with a Powerstat 3PN136B (The Superior Electric Company, Bristol, Conn. USA) and held constant at 120 V once the magnetron had started. For two of the microwave ovens, a fourth IEC test was performed after an additional 10 minute pre-heat to certify that wattage continued to be stable.

Results

Figure 2-1 identifies the microwaves and the wattages measured initially, after a 10 minute pre-heat, after 10 minute pre-heat and heating three successive calzones, and two data points where a second 10 minute pre-heat step was executed. Each data point represents an average of 2 readings.

The overall average wattage drop was 15% from the initial wattage to the average wattage observed during runs 2 and 3. The lowest measured drop was 8% (56 watts) for the Magic Chef, and the highest drop was the Sharp Carousel 2 which dropped 22% (199 watts). This measured drop agrees with literature data regarding wattage output decline as a magnetron heats up (Swain and others 2006, Buffler 1993). The overall average difference between the averages of run 2 and run 3 was 2%. The Amana Radarange has a maximum percent wattage change of 5% between the 2 runs. This demonstrates a stabilization of wattage output following the initial drop which agrees with findings from Swain and others in 2006. The wattages of the 2 microwaves measured after 20 minutes and 3 calzone runs were not different from the measured wattage after 10 minutes and 3 calzone runs, varying by less than 2%. This demonstrated stable wattage period allows for continuous back-to-back testing within a single microwave. Testing in pre-heated microwaves also provides an additional cushion for food safety and would be mimicking potential instances where consumers do utilize microwaves for food preparation that have been in continuous use such as in cafeterias or office break rooms.

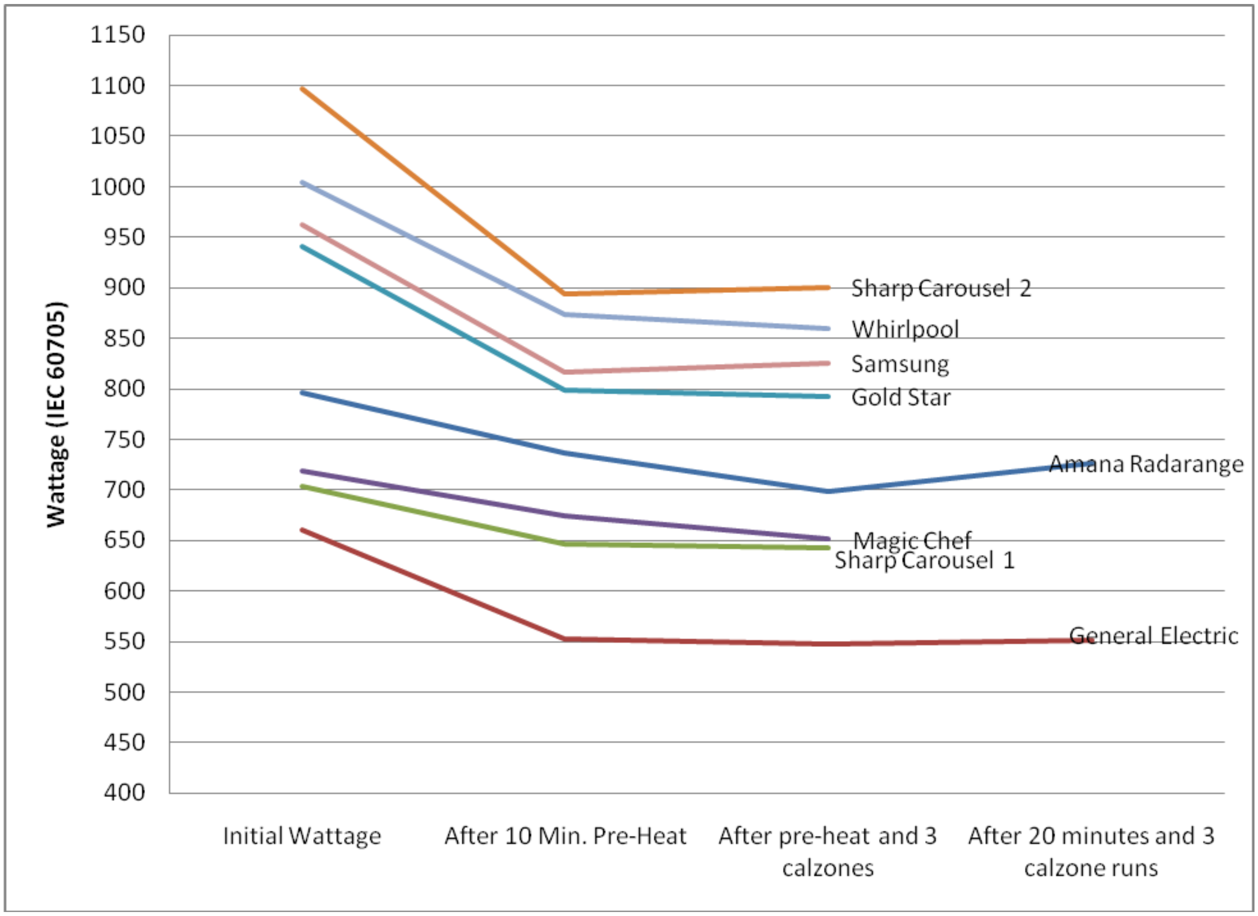

Figure 2-1 – Wattage drop due to pre-heating in eight microwaves.

Conclusions

For the eight microwaves tested, an average decrease in wattage output of 15% was observed after pre-heating and a period of stability with variation less than 5% existed between the pre-heat step and after three calzones and two IEC tests were completed. Utilizing a pre-heat step created a period of stable wattage during which four calzones could be heated in succession in the same microwave. This pre-heat step allows for expedited testing. This experiment included heating only three calzones, however the two IEC tests together account for an additional 2 minutes of heating and thus the ability to heat four calzones in a row in a stable condition.

CHAPTER 3 - Preliminary Study - Effect of Plate Type on Heating of Pizza Products

Abstract

Many foods must be placed on a plate to be heated in a microwave oven. The type of plate chosen by the consumer may influence the final temperature of the heated food. To determine if plate material should be included as a factor in the larger study, various plate materials were evaluated for their effect on final product temperature when used to heat pizza products in the microwave. Five dinner plates (two stoneware, one Corel® glass, and two paper) were evaluated with pizza snacks. Duplicate runs of each plate were tested in each of three microwave ovens ranging in output wattage of 900 watts to 1050 watts. A second study evaluated the effect of three dinner plates, (two stoneware and one paper) on the final temperature of hand-held pizza calzones. For the second study, quadruplicate runs of each plate were tested in two microwave ovens ranging in output wattage of 1000 watts to 1050 watts. For both tests, temperature data was gathered using hypodermic needle probes inserted into the products for 2 minutes after heating in the microwave. The average and lowest maximum temperature for each probe was recorded. For the pizza snacks (average weight per piece = 14g), one probe was inserted in each snack. For the pizza calzone (average weight per piece = 104g), eight probes were inserted into each calzone. In the first test, plate type did not significantly affect the lowest maximum temperature recorded in each probe ($p>.05$). In the second test, product heated on both of the stoneware plates had significantly lower lowest maximum temperatures than product heated on paper plates ($p<.05$). An interaction was also observed between plates and microwaves in the second test indicating that plate effect was not consistent across microwaves. Stoneware and paper plates should be studied as a factor in the larger research study.

Introduction

Foods such as frozen steam-in-bag vegetables and many types of frozen snack items that are packaged in bulk and designed for the consumer to prepare as many or as few as they wish instruct the consumer to heat the foods on a microwavable plate. Consumers may choose from a variety of plate types such as paper, stoneware and glass that are considered microwavable. Most plates sold on the market today have a note on the bottom as to whether they are safe for microwave use. The type of plate chosen by the consumer may influence the final temperature of the heated food. Previous research was not found that addressed the effect of plate type on heating of microwave foods. A preliminary test was conducted to minimize the types of plates which should be tested in the larger study.

Materials and Methods

Five dinner plates were evaluated while heating pepperoni pizza snacks (General Mills, Inc. Golden Valley, MN, USA). The dinner plates were of various materials, weights, and thicknesses (Table 3-2). All were common dinner plates available for purchase at retail stores at the time of the study. Six pizza snacks were placed in a circle on a plate and heated in a microwave on high for 55 seconds for each run. The average weight of the individual pizza snacks was 14.1 g. Duplicate runs of each plate were tested in each of three microwave ovens. The microwaves varied in brand, age and dimensions (Table 3-1). A second study evaluated the effect of three dinner plates, (two stoneware and one paper) on heating of hand-held pizza calzones. They were heated on high for 60 seconds, flipped, and then heated for an additional 30 seconds. The average weight of the pizza calzones was 104.1 g. For the second study, quadruplicate runs of each plate were tested in two microwave ovens.

For both tests, temperature data was gathered using Type-K hypodermic needle probes inserted. For the pizza snacks, one probe was inserted into the center of each snack for a total of 6 probes for each run. For the pizza calzone, eight probes were inserted at various heights into each calzone for a total of eight probes for each run. Temperatures were recorded every 5 seconds for the course of 2 minutes after heating in the microwave. The maximum temperature over the course of the 2 minutes was recorded for each temperature probe, the standard deviation across all the probes for each run was calculated and the lowest maximum across all probes from each run was recorded. Product was stored at -17.8 °C. Power to the microwave was held constant with a Powerstat 3PN136B (The Superior Electric Company, Bristol, CN, USA.). ANOVA analysis was run to determine effect of plate type and microwave. Tukey's studentized range test (HSD) (α=0.05) was used to determine significant differences between the levels of the main effects.

Table 3-1 – Age, wattage, manufacturer, and dimensions of microwaves used in initial plate tests.

Unit	Manufacturer	Age (yrs)	Stated wattage	Measured output wattage (IEC 60705)	Ht (inches)	Width (inches)	Depth (inches)	Volume (cubic feet)
1	A – Maytag	7	1100	1050	8.5	14.5	14.5	1.0
2	O- Samsung	6	1000	1000	9	12.75	13.25	.88
3	Q - Goldstar	5	1000	900	8.5	12.75	13.25	.83

Table 3-2 – Weight, thickness and diameter of plates used in initial plate test.

Plate	Average weight	Plate thickness (mm)	Diameter (cm)	Photo of plate
HOME brand stoneware – used in both tests (Target Corp. Minneapolis, MN)	798 grams	4.9	26.7	
HOME brand stoneware – used in both tests (Target Corp. Minneapolis, MN)	803 grams	5.6	26.7	
Corel® glass plate- used in pizza snack test only (World Kitchen LLC, Rosemont, IL)	326 grams	3.1	25.4	
Chinet® Paper Plate – used in pizza snack test only (Huhtamaki, Inc. De Soto, Kansas)	15.4 grams	0.4	22.4	
Basicware ™ Paper plate – used in both tests (Target Corp. Minneapolis, MN)	6.8 grams	0.3	22.9	

Results and Discussion

In the pizza roll test, significant differences were not found among the five plate types for the average maximum temperature ($p>.05$), standard deviation among the maximums ($p>.05$) or lowest maximum temperature of all probes ($p>.05$) for pizza rolls (Table 3-3). It is thought that two repetitions were not sufficient to distinguish between variables. In addition, since the pizza snacks were heated according to the package directions, which were presumably set to achieve a killstep, the average temperatures were all very high. When temperatures approach 100°C, there is greater difficulty in distinguishing between variables, since a temperature plateau exists around the boiling point.

Significant differences were found among the three microwaves with microwave Q, the lowest output wattage in the set, producing significantly higher average temperatures ($p<.05$), significantly higher lowest maximums ($p<.05$) and significantly lower standard deviation among maximums ($p<.05$). The lower standard deviation was thought to be an artifact of the higher temperatures (Table 3-4). Wattage alone is not a good predictor of temperature, and variability in performance across manufacturers at similar wattages has been demonstrated (O'Meara and Reilly 1986; Dealler and others 1990; Swain and others 2008). For the second study, the repetitions were increased to four and target temperatures were slightly lowered from that which would achieve a killstep. Two plate types, paper plate and blue stoneware, were chosen for testing in the second pizza calzone study.

In the pizza calzone test, significant differences among the three plate types were found for average maximum ($p<.05$), standard deviation (p<..05) and lowest maximum among the probes ($p<.05$). The paper plates produced significantly higher average temperatures, significantly higher lowest maximums and significantly lower standard deviation among maximums than either of the stoneware plates. The stoneware plates were not significantly different from each other (Table 3-5). The two stoneware plates were similar in weight (approx. 800 g) while the paper plates average only 7 grams. This was the likely reason for the difference. The stoneware plates absorbed some of the microwave energy and this slowed down the heating of the food product placed on it. If the blue stoneware plate was heated without any food on it in the microwave, the temperature of the plate would rise slightly indicating it was absorbing some of the microwave energy. No literature references could be found regarding effect of plate type in heating of microwave foods.

Significant differences between the two microwaves were also observed in standard deviation ($p<.05$), and lowest maximum among the probes ($p<.05$), but not in the average maximum temperatures ($p>.05$) recorded for each microwave (Table 3-6).

Table 3-3 – Mean values for average maximum temperature, standard deviation among maximum temperatures, and lowest maximum temperatures for five plate types when used to heat pizza snacks.

Sample	Average maximum temperature (°C)	Standard deviation among maximums	Lowest maximum temperature (°C)
Blue Stoneware	86.3	8.1	73.5
Yellow Stoneware	89.4	7.0	78.4
Corel®	86.1	8.0	74.7
Chinet® Paper	86.3	5.8	77.0
Paper Plate	87.8	5.5	80.0

No significant differences detected (p>0.05).

Table 3-4 – Mean values for average maximum temperature, standard deviation among maximum temperatures, and lowest maximum temperatures for three microwaves used to heat pizza snacks. [a]

Sample	Average maximum temperature (°C)	Standard deviation among maximums	Lowest maximum temperature (°C)
Q - 900 Watts	91.3[a]	4.4[a]	84.4[a]
A - 1000 Watts	86.3[b]	7.4[b]	76.0[b]
O – 1050 Watts	83.9[b]	8.9[b]	69.7[b]

[a] Means with different letters in columns are different (p<0.05).

Table 3-5 – Mean values for average maximum temperature, standard deviation among maximum temperatures, and lowest maximum temperatures for three plate types used to heat pizza calzones. [a]

Sample	Average maximum temperature (°C)	Standard deviation among maximums	Lowest maximum temperature (°C)
Paper Plate	92.7[a]	5.4[a]	82.6[a]
Yellow Stoneware	85.2[b]	12.8[b]	60.2[b]
Blue Stoneware	84.0[b]	12.3[b]	56.8[b]

[a] Means with different letters in columns are different (p<0.05).

Table 3-6 – Mean values for average maximum temperature, standard deviation among maximum temperatures, and lowest maximum temperatures after heating in microwave for two microwaves used to heat pizza calzones. [a]

Sample	Average maximum temperature (°C)	Standard deviation among maximums	Lowest maximum temperature (°C)
A - 1000 Watts	87.2[a]	12.0 [a]	72.8 [a]
O – 1050 Watts	87.7[a]	8.0[b]	63.1[b]

[a] Means with different letters in columns are different (p<0.05).

A significant interaction effect between plate type and microwave was observed in the calzone study. This interaction effect was significant for the standard deviation ($p<.05$) and for the lowest maximum ($p<.05$). The highest temperatures were found in product heated on paper plates, regardless of microwave and for the product heated on the stone ware plates, the standard deviation was higher in microwave A (Figure 3-1). The standard deviations among the maximums reflect the average temperatures. The higher the average temperatures were, the lower the standard deviations. This is thought to be an artifact of the boiling point "ceiling" rather than an indication of greater or lesser uniformity.

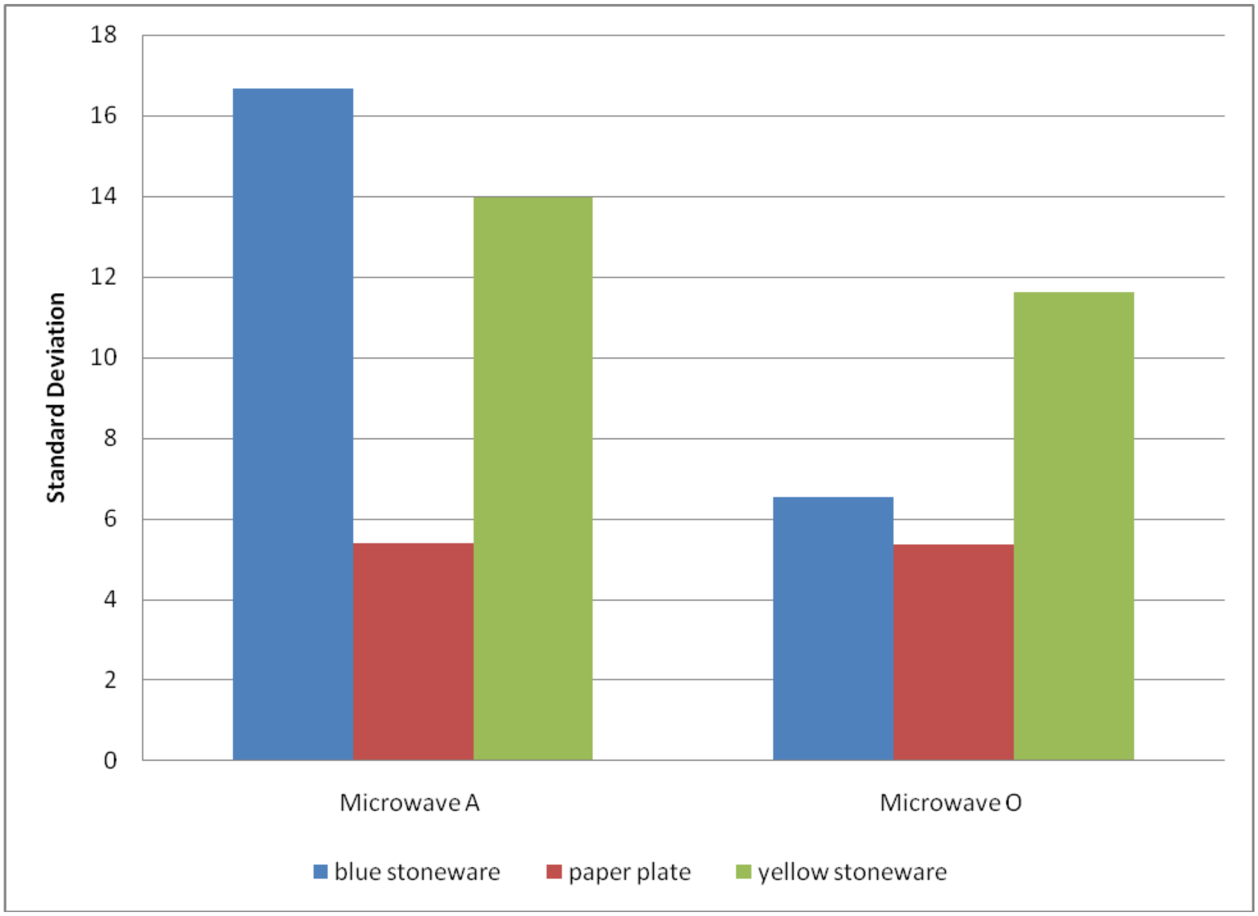

Figure 3-1 – Interaction effect of plate type and microwave on standard deviation of average maximum temperatures of calzones in plate type study.

A similar interaction effect was observed with the lowest maximum temperatures where lowest maximum temperatures were not affected by microwave when heating on a paper plate, but were affected by microwave when heating on a stoneware plate (Figure 3-2). This may indicate that some microwaves are more sensitive to plate type configurations. The two stoneware plates while weighing much the same and having similar shape, did have different designs with the yellow plate having a ridge and the blue plate having a design with raised dots around the perimeter. The design may have caused a difference in performance.

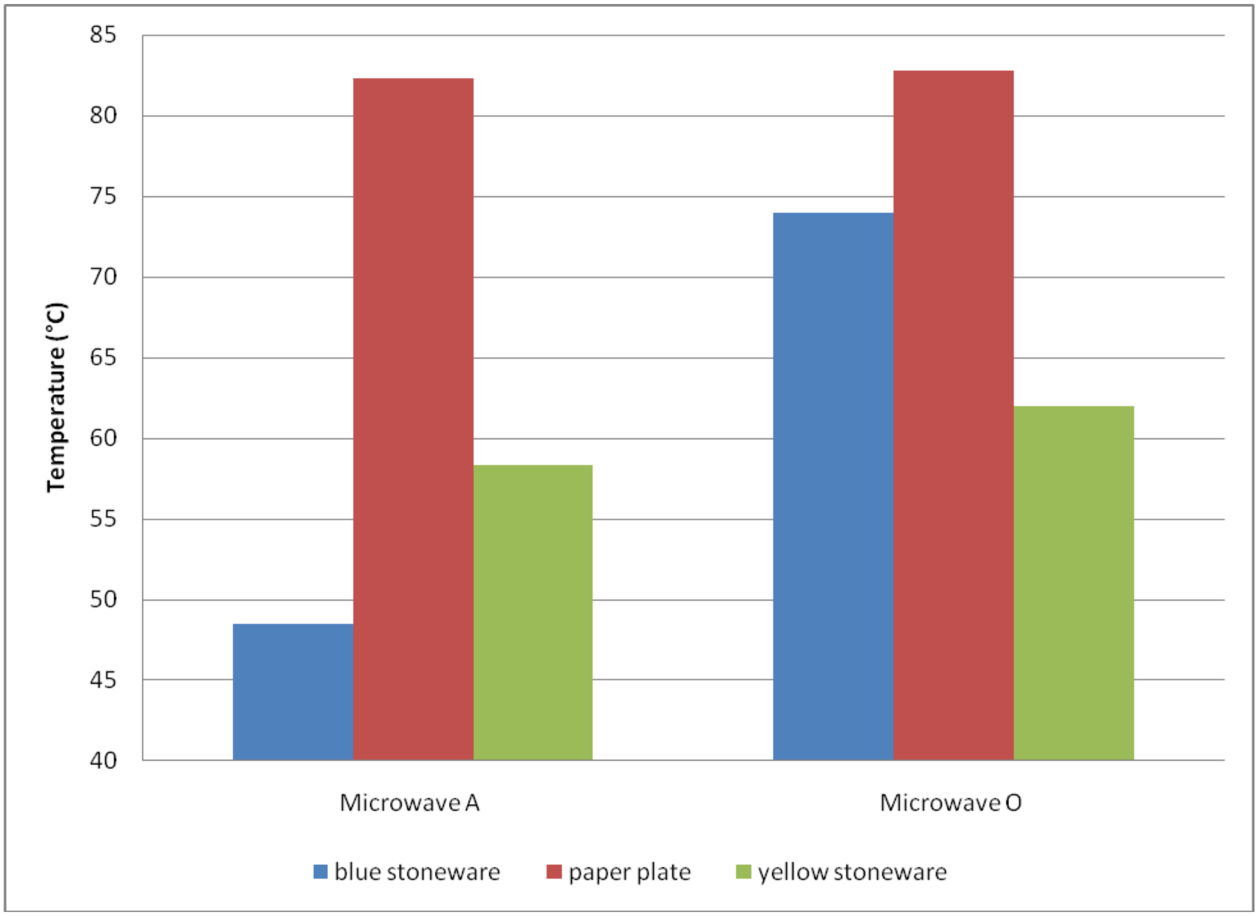

Figure 3-2 – Interaction effect of microwave and plate type on lowest maximum temperature response for calzones in plate type study.

Conclusions

Plate type had a significant effect on temperatures of pizza calzones but not pizza snacks heated in microwave ovens. The number of replications was increased for the second study with calzones and may have increased the sensitivity so that differences could be detected. The microwave had significant effects on lowest maximum and standard deviation with the lowest power microwaves producing the hottest final temperatures in both tests. For average maximum, the microwave effect was only significant in the pizza snacks test. An interaction was observed in the pizza calzone study between plate type and microwave oven indicating that plate type behavior across microwaves was not consistent. Microwaves which produced the highest temperatures always had the lowest standard deviation which was not thought to be related to better uniform heating, but rather an artifact of reaching close to the boiling point of water. For the larger study, stoneware and paper plates should provide the greatest degree of difference in performance and should be included as a factor in the larger study. For the stoneware plates, a design should be chosen which has minimal variations in the surface. The simplest design would be best.

CHAPTER 4 - Factors Affecting Heating of Calzones in Microwaves

Abstract

An understanding of the factors that may affect a consumer's ability to achieve a killstep when cooking microwavable not-ready-to-eat foods is critical to determining the optimum cooking instructions for food safety. Factors are often studied in isolation or within a single microwave. The least-studied factors appear to be those that are controlled by the consumer. Consumer-driven factors that may affect a consumer's ability to achieve a killstep when cooking not-ready-to-eat foods in the microwave were studied. Microwave appliance, heat time, flip step, and plate material were studied to determine their effect on final temperature of a frozen hand-held calzone sandwich after heating. The calzone was heated on a plate for 1 minute, then flipped or not flipped and heated again for the remaining time in each of four microwave ovens. A full-factorial experimental design (4x3x2x2) was executed in duplicate. Fourteen hypodermic needle probes were attached to a data logger and temperatures were recorded every 5 seconds for 2 minutes post-heating to attain the average maximum temperature and lowest maximum temperature for each run. The data was evaluated by analysis of variance and significant differences were compared using Tukey means. All factors had significant effects on average maximum temperature and lowest maximum temperature with the exception of the flip step. Plate type was the most critical factor. Calzones heated on paper plates were significantly hotter than those on stoneware plates. Significant differences were also observed among microwaves and heat times. An interaction between microwave and plate type indicate the effect of plate type is not consistent across all microwaves. These results suggest that the plate chosen by the consumer can have a critical effect on whether killstep is achieved when following the cooking instructions. Stoneware plates would be the most conservative choice for developing cooking instructions from a food safety perspective. Multiple microwaves in this wattage range should be used for development because wattage alone cannot predict performance and because of the interaction between microwave and plate type. Although flip step, as tested, was not a significant factor, a follow-up experiment should be conducted to de-couple the effect of the

physical flipping of the calzone and the stopping of the microwave since all runs in this experiment were stopped during the heating process.

Introduction

Background

This experiment was executed to understand how various consumer-driven factors affect microwave heating of a calzone. Understanding the impact of these factors is critical to developing a validation program for consumer instructions as mandated by the USDA for NRTE foods. Without this understanding, all factors must be considered and studied which is very time consuming. The list of potential sources of variation includes product weight, product temperature, appliance, wattage, flip step, heat time and plate type. Product weight was not chosen as a factor since it is not consumer-related. The initial product temperatures were not studied as a factor but rather were set at a temperature (0°F) which is equal to or lower than 83% of home freezer temperatures (EcoLabs 2007). The other factors were all chosen for study. A frozen food item manufactured on a production line was chosen for study over a model system to make the research as applicable as possible and to capture the inherent variability that is always a constant when developing consumer instructions for NRTE food items. Studies using model systems would not be sufficient for proof of validation; plant-produced food samples are necessary. Previous testing in Chapter 3 established protocol for using pre-heated microwaves for this testing. The experiment in Chapter 4 helped to narrow down the plate types that would be studied.

Objectives

This research aims to understand the impact of several consumer-driven factors on heating of a calzone in the microwave. These include plate material, heat time and flip step. These consumer-influenced factors are some of the least studied among the factors affecting heating rates for microwave products. Previous testing has been generally limited to one microwave; however, this research will test the effect of factors across a wide range of microwaves which is a far better predictor of what will happen in consumers' homes. It is hypothesized that while many factors affect heating rate, most are minimal in comparison to the differences between microwaves even within a wattage category. An understanding of the relative importance of certain factors would allow for the creation of optimized testing protocol. This information will be valuable to anyone engaged in testing and validating cooking instructions.

Materials and Methods

Product

The frozen NRTE hand-held calzone sandwich consisted of an outer crust of bread and an interior pizza filling with sauce, cheese, and meat components. It is wrapped in plastic and sold in cartons of 4 or 12 calzones. The product was supplied by General Mills, Canada Corporation, Toronto, CAN. The ingredients were: enriched wheat flour, water, pizza topping (water, palm oil, rennet casein, modified potato starch, salt, milk ingredient, sodium phosphate, sodium aluminum phosphate, lactic acid, sorbic acid, colour [contains modified coconut oil], flavour), cooked pepperoni and bacon, canola oil, tomato paste, salt, sugar, baking powder, modified corn starch, monoglycerides, whey powder, garlic and onion powder, flavour, spice, xanthan gum, soybean oil, l-cysteine hydrochloride. The calzones were approximately 2.3 cm thick, 11.5 cm long and 6.3 cm wide. The shape was a half-circle. The average weight was 104 g and the dough-to-filling ratio by weight was approximately 40:60.

The cooking instructions were:

1. Place on microwave-safe plate.
2. Microwave on HIGH for 1 minute.
3. FLIP product over and microwave additional 15 to 30 seconds.
4. Let stand 1 minute.

The product was stored at -17.78 °C. This temperature was at or colder than 83% of home freezers according to the EcoSure 2007 U.S. Temperature Evaluation study.

The exact manufacturing process of the product is proprietary; however it is known that NRTE products do not either receive sufficient killstep during the process or are not handled in a manner consistent with RTE products after a killstep is achieved and thus are sold as NRTE products. For this reason, consumer directions must demonstrate a killstep.

Experimental Design

The experimental set-up was a full factorial design with four factors. There were four microwaves, three heat times, two conditions for the flip step and two plate materials. This resulted in a 4x3x2x2 design with 48 microwave runs. Each run was performed with two replications for a total of 96 runs. The design was executed in six separate sessions of 16 runs, with 4 runs per microwave in each session. For each microwave a pre-heat step was employed followed by 4 test runs. There was a minimum rest period of 5 hours between each session. The pre-heat step allowed for multiple runs to be performed in a period of stable output wattage without a rest period between runs. The testing to establish the validity of this pre-heat step is documented in Chapter 3. The order of runs for each session was randomized within each microwave and across the sessions. Power to the microwave was controlled with a Powerstat 3PN136B (The Superior Electric Company, Bristol, CN, USA.) and held constant at 120 V once the magnetron had started.

Factors

Microwave Ovens

The four microwave ovens represent typical consumer microwaves sold in the U.S. over the past 7 years in the lowest wattage range and varied by brand, age, and dimensions (Table 4-1). Each microwave had a turntable that was utilized during testing. The microwave output wattage was measured using the IEC 60705 (Ed. 3.2, 2006) 1 L water test.

Table 4-1 – Brand, age and dimensions of low-wattage microwave ovens used in the study.

Unit	Manufacturer	Stated Wattage	AGE of Microwave (yrs)	Measured Output Wattage (IEC 60705)	Ht (inches)	Width (inches)	Depth (inches)	Volume (cubic feet)
1	Amana Radarange	800	7	700	7.8	11.8	11.3	.6
2	GE	700	1	550	7.1	11.5	10	.5
3	Sharp Carousel	800	4	650	7.4	11.9	12.1	.8
4	Magic Chef	800	1	650	8.3	11.4	12	.7

Flip Step

The cooking instructions direct the consumer to flip the product over in step 3 after 1 minute of heating. For both treatments, the calzone was first heated for 1 minute on high. The door was opened, and in half the runs the product was flipped at this point and in half the runs the product was left untouched. The door was then shut and the product was further heated on high for the remainder of the time appropriate to that run.

Microwaveable Plate

The plates were chosen from a set of typical consumer plates available at retail at the time of the study. An initial test with pizza snacks and pizza calzones were used to narrow down the plate type options to 2. The initial plate tests are described in Chapter 2. The 2 treatments for this factor were a paper plate, 9" diameter, Basicware™ brand uncoated paper plate, (Target Corp. Minneapolis, MN, USA), and a 10" diameter, Room Essentials ™ brand diameter stoneware plates, (Target Corp. Minneapolis, MN, USA). The average weight of the paper plate was 6.8g and the stoneware plate was 602.9g. The stoneware plates had no design with any raised features and were completely smooth on the top surface.

Time

The time range used in this study was pre-determined by test runs in these microwaves which identified the approximate time that would approach killstep but not overheat the product and destroy the quality. The 3 times chosen for this wattage range were 100 seconds, 110 seconds and 120 seconds. For each run, 1 minute was entered into the control panel of the microwave and the start button was pushed. After 60 seconds, the flip step was either employed or not, and the calzone was heated on high for the remainder of the time appropriate to the run (40 seconds for a 100 second run, 50 seconds for a 110 second run and 1 minute for a 120 second run).

Data Collection

An apparatus was built using a ½" thick plastic platform supported by four 2 1/2" tall metal legs. The plate measured 4" x 5" with fourteen ¼" holes drilled across the top to allow for hypodermic needle probes to be inserted at varying depths to record temperatures. The probes were Omega® HYP3-16-1-1/2-k-g-48-PR probes and the dimensions are given in Figure 4-1.

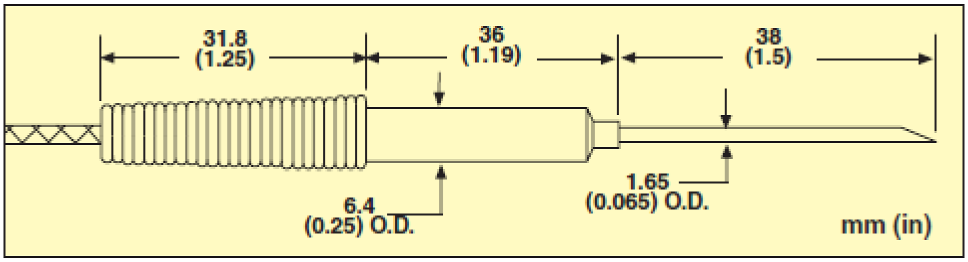

Figure 4-1 – Diagram of individual thermocouple probe.

Figure 4-2 is a side view picture of the platform with the probes attached. These probes were attached to a Fluke Universal Input Module inserted into a Fluke Data Logger (Fluke Hydra Series II).

Figure 4-2 – Side view of probes attached to platform.

Probes 1, 2, and 3, in addition to 12, 13 and 14 were spaced 32.75mm apart. Probes 4 and 5 and 10 and 11 were 32.5 mm apart. Probes 6, 7, 8 and 9 were 10.8mm apart. Each row was approximately 10mm apart (Figure 4-3). The probe heights, as measured from the surface the calzone was resting on, varied in a random fashion since it was unknown before-hand where hot and cold spots would be located (Table 4-2).

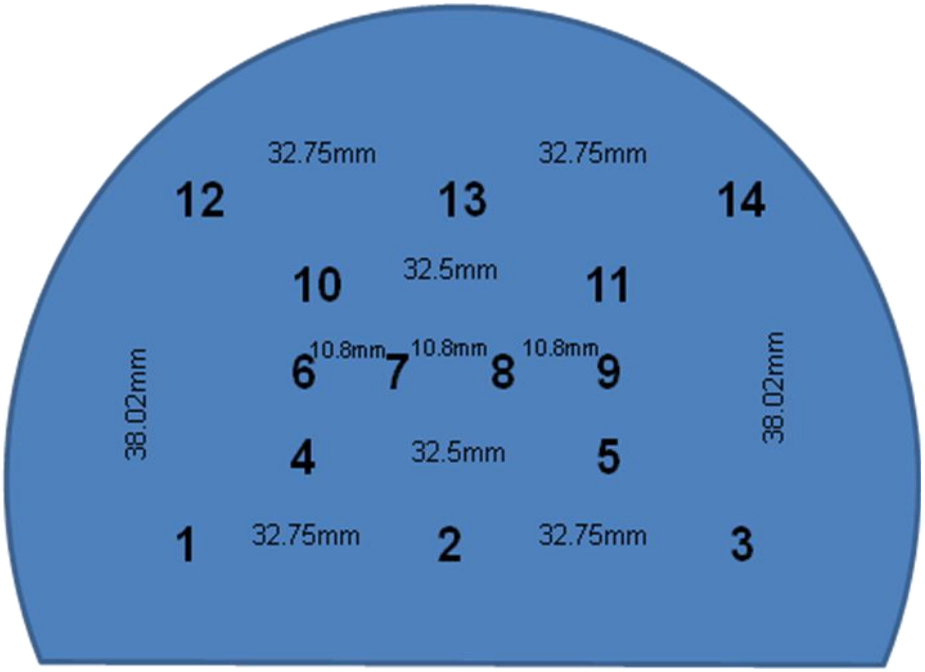

Figure 4-3 – Schematic of probe locations.

Table 4-2 – Height from surface of individual temperature probes in millimeters.

Probe	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Height (mm)	5.8	8.1	6.7	6.7	10.1	7.9	10.3	6.4	7.8	6.6	12.1	9.7	9.2	11.6

The data logger was attached via null modem cable to a laptop computer (Compaq nc6230, Compaq Corp.). Hydra Logger software (version 3.0, Copyright Fluke Corporation, 1996) was used to collect the data in a .csv file which could be opened by Excel® and sorted.

Responses

For each run, immediately after heating (<30 s), the calzone was removed and the apparatus was placed on top of the calzone. The exact placement of the apparatus was guided by markings on each plate made with a template to match the position of the calzone and legs of the probe apparatus. Temperatures of each probe were measured every 5 seconds over a period of 2 minutes post-heating in the microwave using the probe apparatus. This method allowed for the determination of the maximum temperature achieved in each probe during the 2 minutes post-heating. Grams of filling lost and percent weight loss were tracked in order to determine if they would be good predictors of temperature. The grams of filling lost were calculated by weighing the amount of filling that leaked onto the plate after heating. In order to calculate percent weight loss, the final weight of the calzone after heating consisted of the weight of the heated calzone plus the grams of filling that leaked onto the plate. Time to reach maximum temperature was recorded to determine how long the stand time should be post-heating for food safety. Probe position was tracked in order to determine if any of the variables had an effect on uniformity. The responses measured are listed in Table 4-3.

Table 4-3 – Responses measured and how measurements were obtained for factors affecting heating in low-wattage microwave.

Responses	How measurement was obtained
Average Maximum	Maximum temperature recorded across the 14 probes during the 2 minutes post-heating
Standard Deviation among Maximums	Standard deviation of the 14 maximums recorded for each run
Lowest Maximum of all Probes	Lowest maximum recorded from the 14 maximums from each run (indicative of whether killstep was achieved)
Grams of Filling Leaked	Measured in grams by weighing the plate before and after heating to measure the grams of filling that leaked onto the plates during heating.
Percent Weight Loss	Calculated from measuring the calzone before and after heating. The grams of leaked filling were added back to the final weight of the calzone to get the total weight loss during heating.
Probe Position	Interior Probes (4-11) versus Exterior Probes (1-3, 12-14)
Probe Depth	Probes 1,3,4,6,8,9,10 (below 8mm) versus probes 2,5,7,11,12,13,14 (higher than 8 mm)
Pass Killstep	Runs were considered to have passed killstep if the

	lowest maximum was at or above 71.1 °C. In addition, runs where the lowest maximum was above 65 °C, the AMFI Lethality spreadsheet was used to calculate lethality.
Time to Reach Maximum	Number of seconds to reach the maximum temperature during the 2 minutes post heating

The steps for gathering the data are listed below:

1. Microwave is pre-heated using 1,000g of 4°C water in glass bowl on high for 10 minutes.
2. Sides of microwave are wiped down and turntable is cooled to room temperature in a water bath.
3. Calzone is removed from -17°C storage and placed on room temperature plate.
4. Plate and calzone are weighed.
5. Plate and calzone are placed in center of microwave turntable and heated on high for 1 minute.
6. Door is opened; calzone is flipped, or not flipped, and heated for remainder of time appropriate to that run.
7. Temperature probe apparatus is placed on top of calzone and temperatures are recorded every 5 seconds for 2 minutes post-heating.
8. Calzone is weighed.
9. Plate is weighed and difference from initial weight is recorded as grams of filling leaked.

An example of run data from a typical run is exhibited in Appendix A.

Data Analysis

Analysis of Variance (ANOVA) was performed on the data to determine the effect of the factors using SAS® version 9.1 (SAS Institute, Inc. Cary, NC, USA). Each factor was tested against the responses and significant differences were noted. When significant differences were detected, Tukey's Standardized Range test (HSD) (α=0.05) was used to determine which levels of the factor were different from each other. The weight of each calzone was recorded and was included as a covariate in the GLM model for increased precision in determining the effect of the factors on the responses.

Results and Discussion

Microwave Oven

There were significant differences found in average maximum ($p<.05$), standard deviation of maximums ($p<.05$), and lowest maximum ($p<.05$), among the four microwave ovens. Microwave 1 with output of 700 watts had significantly higher average temperatures and significantly higher lowest maximums compared to microwaves 3 and 4 which each had measured output wattages of 650. Microwaves 1 and 2 (output = 550 watts) were not significantly different from each other in any of the 3 responses related to maximum temperature. Microwaves 3 and 4 were not significantly different from each other in any of the 3 responses related to maximum temperature (Table 4-4).

Table 4-4 – Mean values for the average maximum temperature, standard deviation among average maximums and lowest maximums for calzones heated in four low-watt microwaves. [a]

Microwave	Average maximum temperature (°C)	Standard deviation among maximums	Lowest maximum temperature (°C)	Measured wattage output (IEC 60705)
1. Amana Radarange	83.0[a]	11.6[a]	62.7[a]	700
2. GE	80.1[ab]	13.0[a]	59.1[ab]	550
3. Sharp Carousel	79.3[b]	15.5[b]	52.8[bc]	650
4. Magic Chef	77.5[b]	17.1[b]	45.7[c]	650

[a] Means with different letters in columns are different ($p<0.05$).

There were significant differences found in filling leakage ($p<.05$) among calzones heated in the four microwave ovens. Calzones heated in microwave 1 had significantly higher grams of filling leaked (7.9g) compared to microwave 2 (4.8g). Microwaves 3 and 4 (5.6g and 6.4g) were not significantly different from either microwaves 1 or 2 and were not significantly different from each other (Table 4-5).

There were also significant differences in percent weight loss ($p<.05$) among the calzones heated in the four microwaves with microwaves 1, 3 and 4 having significantly higher weight loss than calzones heated in microwave 2 (Table 4-5).

Table 4-5 – Grams of filling leaked and percent weight loss for calzones heated in four low-wattage microwaves. [a]

Microwave	Grams of filling leaked	Percent weight loss
1 – Amana Radarange	7.9^{a}	7.0^{a}
3 – Sharp Carousel	5.6^{ab}	7.0^{a}
4 – Magic Chef	6.4^{ab}	6.6^{a}
2 –GE	4.8^{b}	4.1^{b}

[a] Means with different letters in columns are different ($p<0.05$).

Significant differences among the microwaves did not necessarily correspond to measured wattage output as the microwave of 700 watts and 550 watts did not differ from each other and were the highest and lowest wattages in the set. O'Meara (1986) also found that time required to heat was not directly related to measured power output. Calzones heated in microwave 2 (GE microwave, 550 watts), the smallest microwave in the set, had higher temperatures than 2 of the other microwaves and calzones heated in microwave 2 had less weight loss and less filling leakage. The size of the calzones was 104 grams which was a relatively small load for microwaves, especially higher powered microwaves. Some ovens may be designed to work best with smaller loads, therefore actually performing better than ovens that are measured at higher output wattages (Schiffmann 1993). Studies undertaken by IMPI and Gerling laboratories in the 1980's, illustrated this point by measuring output wattage of 31 random microwaves at six different load sizes. Although the best-fit line was linear, large deviations from the line did occur. Further investigation revealed that the most common contributor to the variation was load volume followed by magnetron specifications, power supply, load geometry, load temperature, cavity size, cavity geometry, and cavity material (Buffler 1991).

Oven design parameters that may affect heating are not necessarily visible to the consumer or even non-microwave experts. Cavity material may affect the amount of absorbed energy and design features such as stirrers, cavity shape, turntable elevation, and filament construction can play a role as well (Buffler 1993). Therefore; it is not easy to establish why a particular oven may heat better than another of similar size and wattage. Any standard consumer microwave from the retail market must be considered valid for the purposes of killstep testing.

Regarding filling loss and weight loss, if the product were seamed perfectly without holes or breaks for the filling to leak out, you might expect that the higher the temperature, the more leakage there would be. Temperatures of calzones heated in microwaves 1 and 2 did not differ significantly; however, filling loss was significantly different. The conclusion is that the seaming of the product was not perfect and varied randomly.

Heat Time

There were significant differences found in average maximum ($p<.05$), standard deviation of maximums ($p<.05$), and lowest maximum ($p<.05$), among the three heat times tested. The average maximum and standard deviation were significantly different for each of the heat times tested. Increasing the heat time from 100 seconds to 110 seconds increased the average maximum temperature 4.3°C and decreased the standard deviation 1.2°C. Increasing the heat time a further ten seconds increased the average maximum another 3.5°C and decreased the standard deviation another 2.7°C (Table 4-6).

Heat times as little as ten seconds can be significant. If a product has a heat time of "1 minute, 10 seconds" it is important to recognize that consumers who like to employ a "minute" button may consider that "minute" sufficient heating for the product.

Table 4-6 – Mean values for average maximum temperature, standard deviation among maximum temperatures and lowest maximum temperatures for calzones heated for 100, 110, and 120 seconds. [a]

Time	Average maximum temperature (°C)	Standard deviation among maximums	Lowest maximum temperature (°C)
120 s	83.7[a]	12.1[a]	61.6[a]
110 s	80.3[b]	14.8[b]	54.0[b]
100 s	75.9[c]	16.0[c]	49.6[b]

[a] Means with different letters in columns are different ($p<0.05$).

There were significant differences found in grams of filling leaked ($p<.05$), and percent weight loss ($p<.05$), among the three heat times tested. Calzones heated for 120 seconds had significantly higher grams of leaked filling than those heated for only 100 seconds. Calzones heated for 110 seconds did not differ significantly from either the 120 second or 100 second samples. Increasing the heat time from 100 seconds to 110 seconds led to significantly higher percent weight loss, as did increasing the heat time from 110 seconds to 120 seconds (Table 4-7).

Table 4-7 – Mean grams of filling leaked and mean percent weight loss for calzones heated for 100, 110, and 120 seconds. [a]

Time	Grams of filling leaked	Percent weight loss
120 s	7.9[a]	7.8[a]
110 s	5.9[ab]	5.9[b]
100 s	4.8[b]	4.8[c]

[a] Means with different letters in columns are different (p<0.05).

It would be expected that product that is heated longer would have higher temperatures, and thus leak more filling and experience higher percent weight loss. In fact, longer heat times produced higher temperatures, lower standard deviations, higher percent weight loss and more grams of filling leaked. Differences of 10 seconds of heating significantly affected all responses measured, although there was no significant difference in the lowest maximum when going from 100 seconds to 110 seconds. In some cases, an additional 10 seconds was not enough to significantly raise the temperature of the calzone.

Flip Step

No significant difference in average maximum (p>.05), standard deviation of maximums (p>.05), or lowest maximum (p>.05) for the flip step factor were detected. The difference between flipping and not flipping the calzone was approximately 1°C for each response (Table 4-8).

Table 4-8 – Mean values for average maximum temperature, standard deviation among maximum temperatures and lowest maximum temperatures for flipped calzones versus calzones that were not flipped. [a]

Flip Step	Average maximum temperature (°C)	Standard deviation among maximums	Lowest maximum temperature (°C)
Flipped	80.2[a]	14.1[a]	55.6[a]
Not Flipped	79.8[a]	14.6[a]	54.5[a]

[a] Means with different letters in columns are different (p<0.05).

No significant difference in grams of filling leaked (p=.8580), or percent weight loss (p=.4564) were observed (Table 4-9). The average difference between flipping and not flipping the calzone was less than 1 gram of filling leaked and less than 0.5% weight loss.

Table 4-9 – Mean grams of filling leaked and mean percent weight loss for calzones that were flipped versus calzones that were not flipped. [a]

Flip Step	Grams of filling leaked	Percent weight loss
Flipped	6.2[a]	6.3[a]
Not Flipped	6.1[a]	6.1[a]

[a]Means with different letters in columns are different (p<0.05).

It was suspected that flipping the calzone would increase overall temperatures and/or reduce the range of temperatures observed. The act of flipping the calzone mid-way through heating had no effect on any of the temperature responses tested such as averages, standard deviations, lowest maximums, or variability from top to bottom or interior to exterior. The flip step also did not affect weight loss or filling leakage. The process of flipping a product mid-way through heating requires the stopping of the microwave and opening of the door. Therefore, it was not possible to tell if the physical flipping of the calzone or the stopping of the microwave for a brief period was influencing the responses. To execute a flip step, the microwave must be stopped and in this study all runs were stopped at 1 minute regardless of whether the product was flipped or not. This was done so as not to confound the stopping and the flipping, since it was unknown if the stopping of the microwave during the middle of heating had any possible affect on temperatures either. Follow-up work is needed to understand whether the flip step is important when compared to not stopping and not flipping.

Plate Type

There were strong significant differences found in average maximum (p<.05), standard deviation of maximums (p<.05), and lowest maximum (p<.05), between the two plate types. The average maximum temperature of calzones heated on a paper plate was 85.9°C compared to calzones heated on stoneware plates which was 74.1°C. The standard deviation was significantly lower for the calzones heated on paper plates (10.8°C) than when calzones were heated on stoneware plates (17.8°C). The lowest maximum temperature recorded was significantly hotter on paper plates (65.3°C) versus stoneware plates (44.83°C) (Table 4-10).

Table 4-10 – Means values for average maximum temperature, standard deviation among maximum temperatures and lowest maximum temperatures for calzones heated on paper and stoneware plates. [a]

Plate Type	Average maximum temperature (°C)	Standard deviation among maximums	Lowest maximum temperature (°C)
Paper	85.9[a]	10.8[a]	65.3[a]
Stoneware	74.1[b]	17.8[b]	44.8[b]

[a] Means with different letters in columns are different ($p<0.05$).

There were significant differences found in grams of filling leaked ($p<.05$) and percent weight loss ($p<.05$) of calzones heated on paper versus stoneware plates. Calzones heated on a paper plate lost an average of 8.2 grams of filling versus those heated on stoneware plates which lost an average of 4.2 grams of filling. Calzones heated on paper plates also had significantly higher weight loss, 6.75%, versus those heated on stoneware plates which lost an average of 5.58% (Table 4-11).

Table 4-11 – Mean grams of filling leaked and mean percent weight loss for calzones heated on paper and stoneware plates. [a]

Plate Type	Grams of filling leaked	Percent weight loss
Paper	8.2[a]	6.8[a]
Stoneware	4.2[b]	5.6[b]

[a] Means with different letters in columns are different ($p<0.05$).

Of all the factors tested this factor had the most influence on the responses tested as evidenced by the low p-values and the highest F-Values of all the factors. Calzones heated on paper plates had higher temperatures, lower standard deviations, higher percent weight loss and higher filling leakage. The differences were significant in all cases. The paper plates weighed an average of 7 grams while the stoneware plates weighed an average of 603 grams. Although the stoneware plates were marked “microwave-safe”, they appear to have been absorbing some of the microwave energy and thus blocking energy from reaching the calzone. Heating one of the stoneware plates in the microwave for 20 seconds confirms there was some amount of absorbance since the empty plate heated slightly. In these low-watt microwaves, the plates were sometimes as large as the turntables inside. The microwaves were not as efficient at heating the calzone when the stoneware plate was in the cavity. This has implications for designing the best and the safest microwave directions. If directions were developed on a stoneware plate, the consumer who chooses a paper plate to heat their product may over-heat and experience a quality reduction.

Interactions

Significant interactions were detected between the microwave and plate type in average maximum ($p<.05$), standard deviation of maximums ($p<.05$), and lowest maximum ($p<.05$). For microwave 1, there was little difference between the average maximum when heated on a paper plate or a stoneware plate. For the other three microwaves, the calzones heated on stoneware plates had much lower average maximums (Figure 4-4). Standard deviation of average maximums for calzones heated in microwaves 1 and 3 again did not differ greatly across plate types whereas calzones heated on stoneware plates in microwaves 2 and 4 had much higher standard deviations and colder temperatures (Figures 4-5, 4-6). For the average maximum, a three-way interaction was also found to be significant between microwave, flip step and plate type ($p<.05$). In microwave 1, flipped and not flipped product was slightly colder on stoneware plates. For microwave 2, flipped calzones were hotter than not flipped calzones when prepared on paper plates, and colder when prepared on stoneware plates. In microwave 3, flipped and not flipped products were similar when prepared on paper plates, but on stoneware plates, not flipped product was colder. In microwave 4, results were again similar on paper plates, but this time on stoneware plates, the flipped calzones were much colder (Figure 4-7). Microwave 1 appears to be more consistent in heating regardless of conditions such as plate type and flip step. Heating in microwave 2 was more affected by factors such as plate type and flip step. Although these microwaves are similar, there are design differences which may make their more or less efficient, and more or less consistent in their heating.

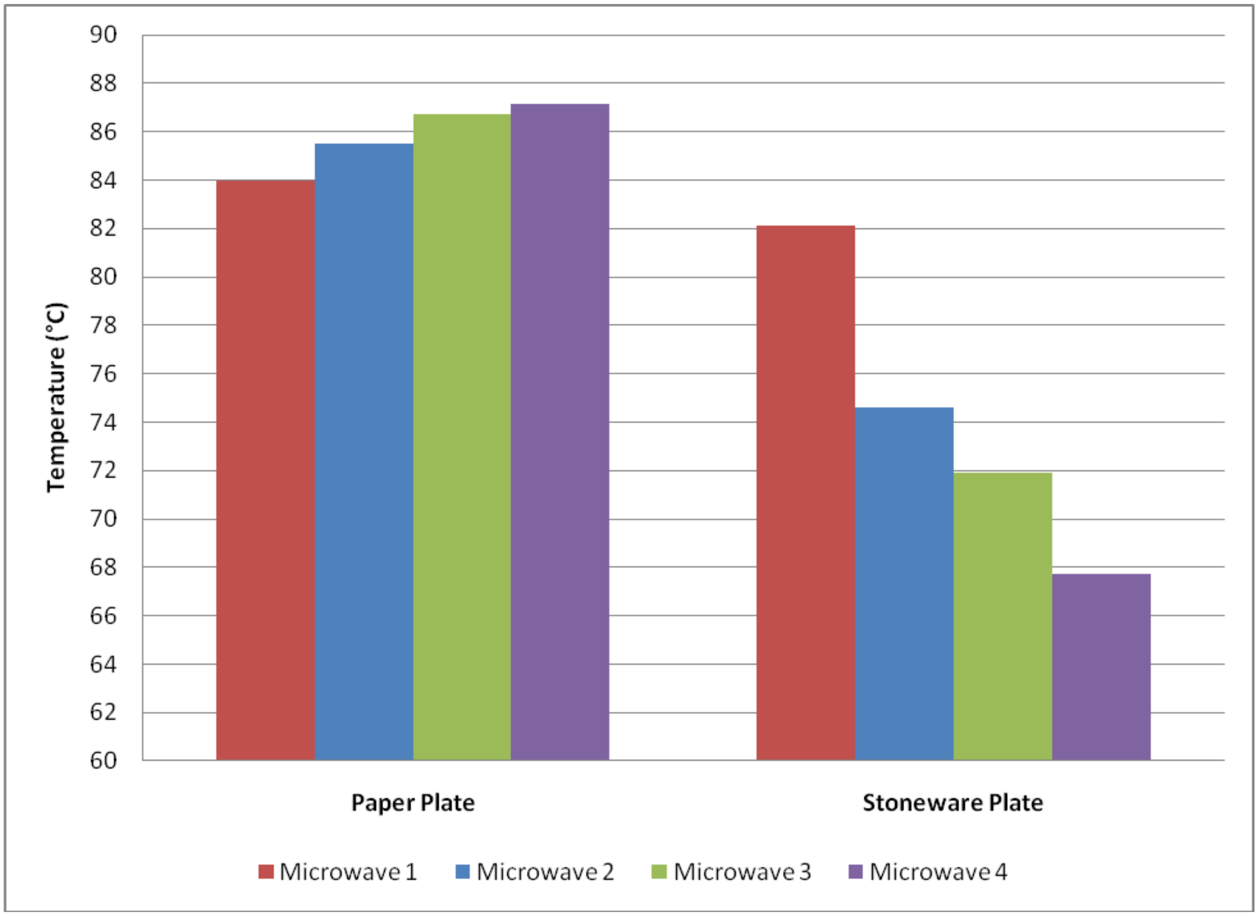

Figure 4-4 - Interaction effect of plate type and microwave on average maximum temperature of calzones in low-watt microwave study.

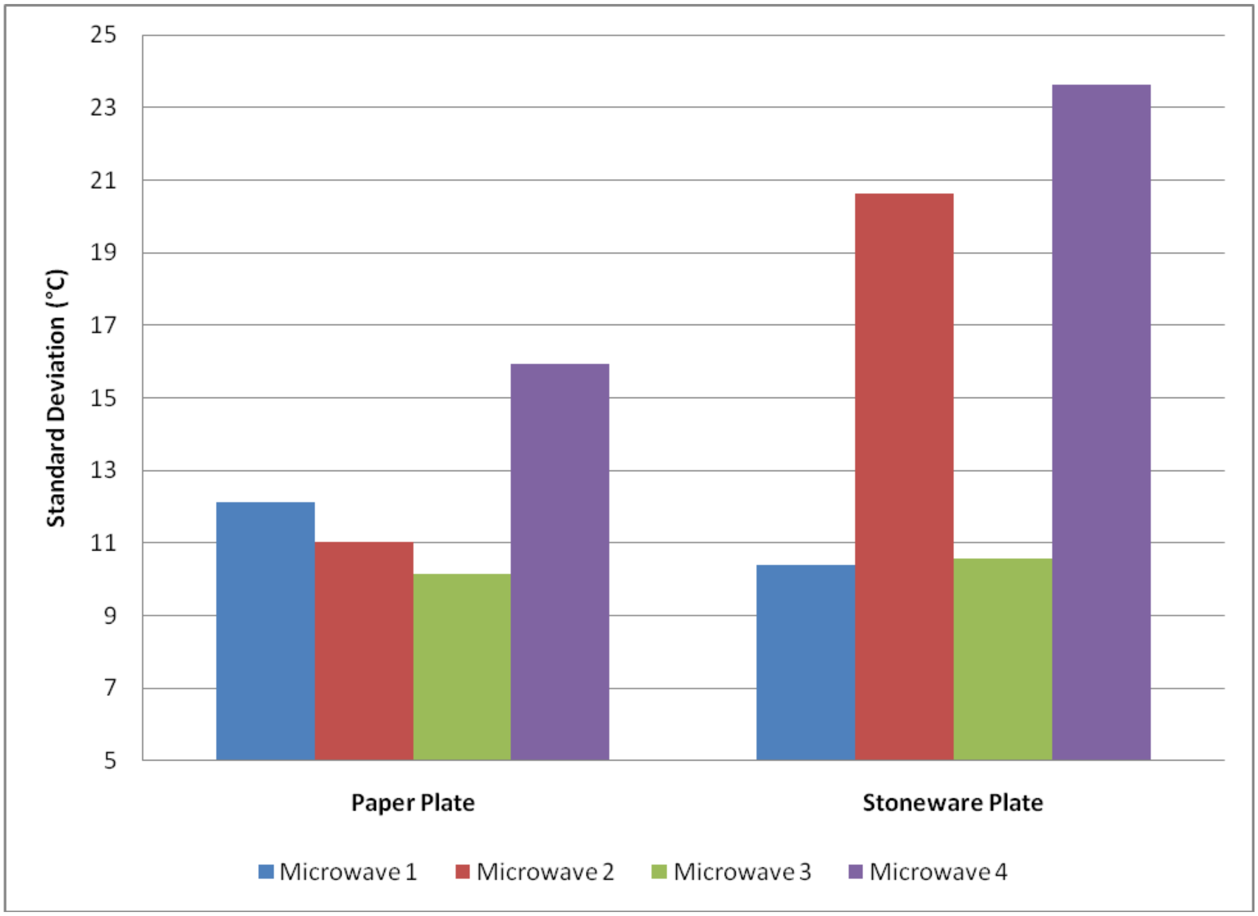

Figure 4-5 – Interaction effect of plate type and microwave on standard deviation among maximum temperatures of calzones in low-watt microwave study.

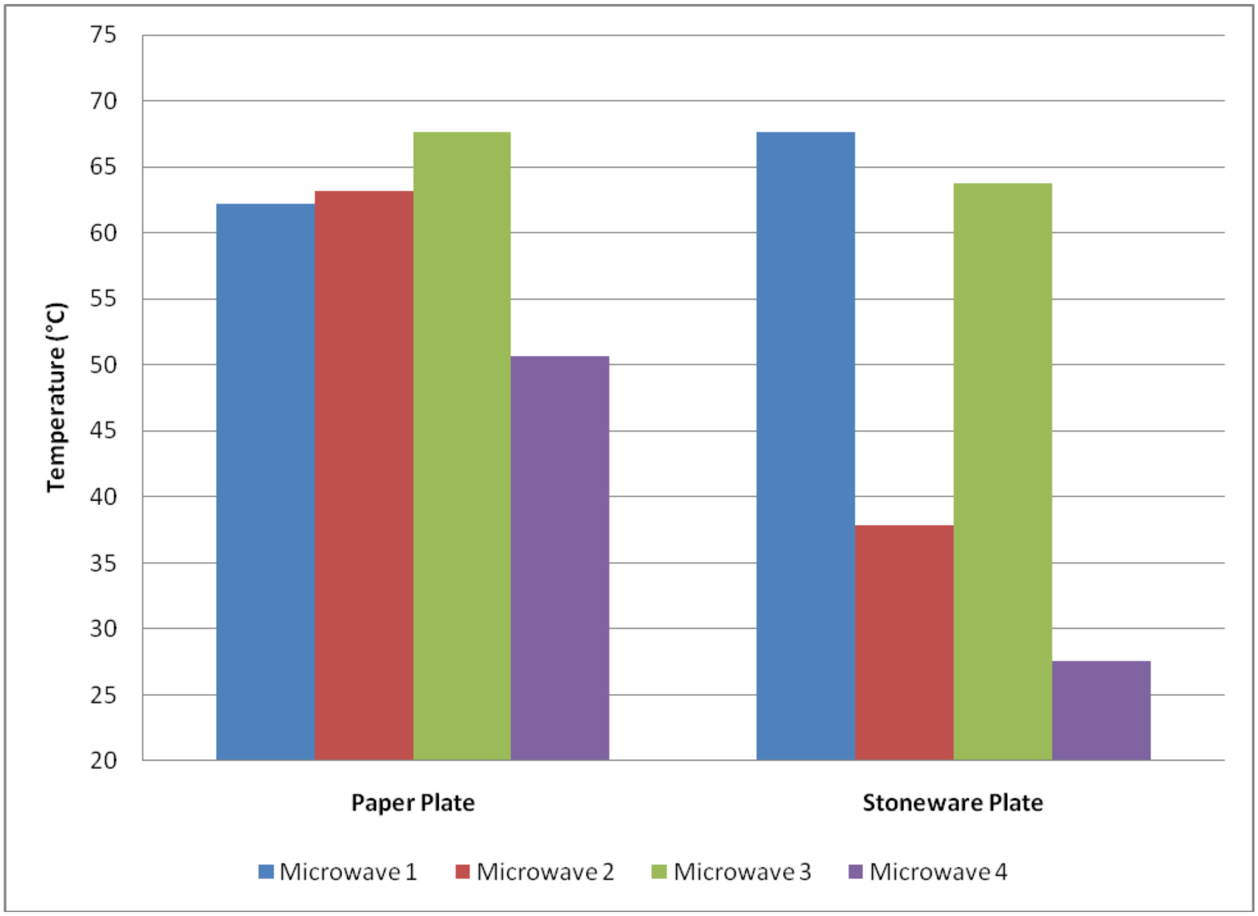

Figure 4-6 – Interaction effect of plate type and microwave on lowest maximum temperatures of calzones in low-watt microwave study.

A significant interaction was detected between the microwave and plate type in grams of filling leaked ($p<.05$). Calzones heated in microwaves 2, 3, and 4 had lower filling loss when heated on a stoneware plate compared to paper plates, however; calzones heated in microwave 1 did not differ in grams of filling leaked across plate types (Figure 4-8). The interaction effect illustrated that calzones heated similarly in microwave 1 regardless of the plate type and this resulted in no change to the temperature responses or the grams of leaked filling. In microwaves 2, 3, and 4, the calzones heated much hotter when on paper plates compared to stoneware. Microwave 1 was the highest output wattage of the set but not the largest cavity size. It was much better at heating the calzone on a stoneware plate and that may just be inherent to the appliance. There were no other identifiable differences in this microwave that may explain these results.

The many significant interactions observed throughout this test imply that the factors that affect heating are not predictable or consistent across even a small set of four randomly chosen microwaves. Testing should include as many microwaves as possible to ensure that interactions are observed and understood.

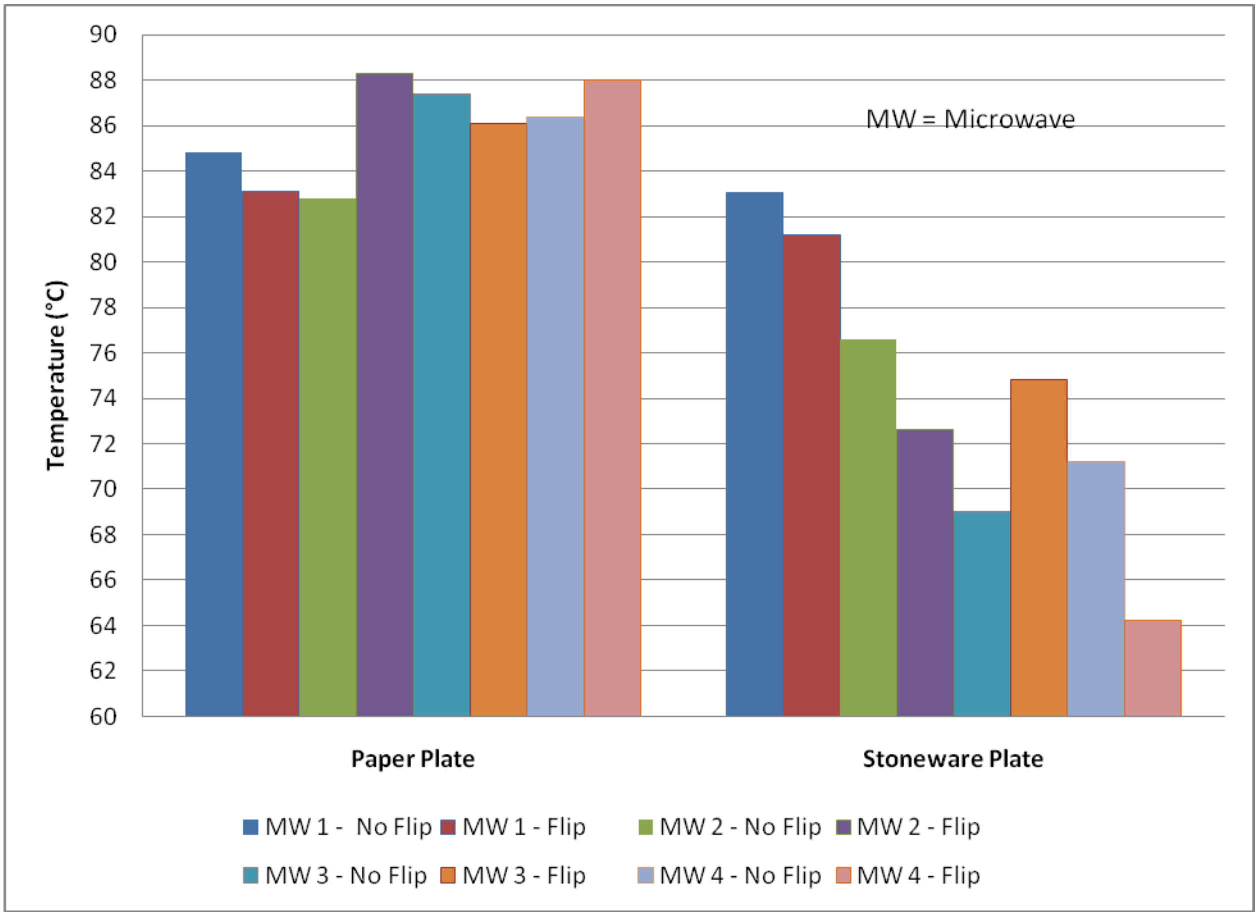

Figure 4-7 – Average maximum temperatures of calzones in low-watt microwave study plotted for microwaves and flip step across plate types.

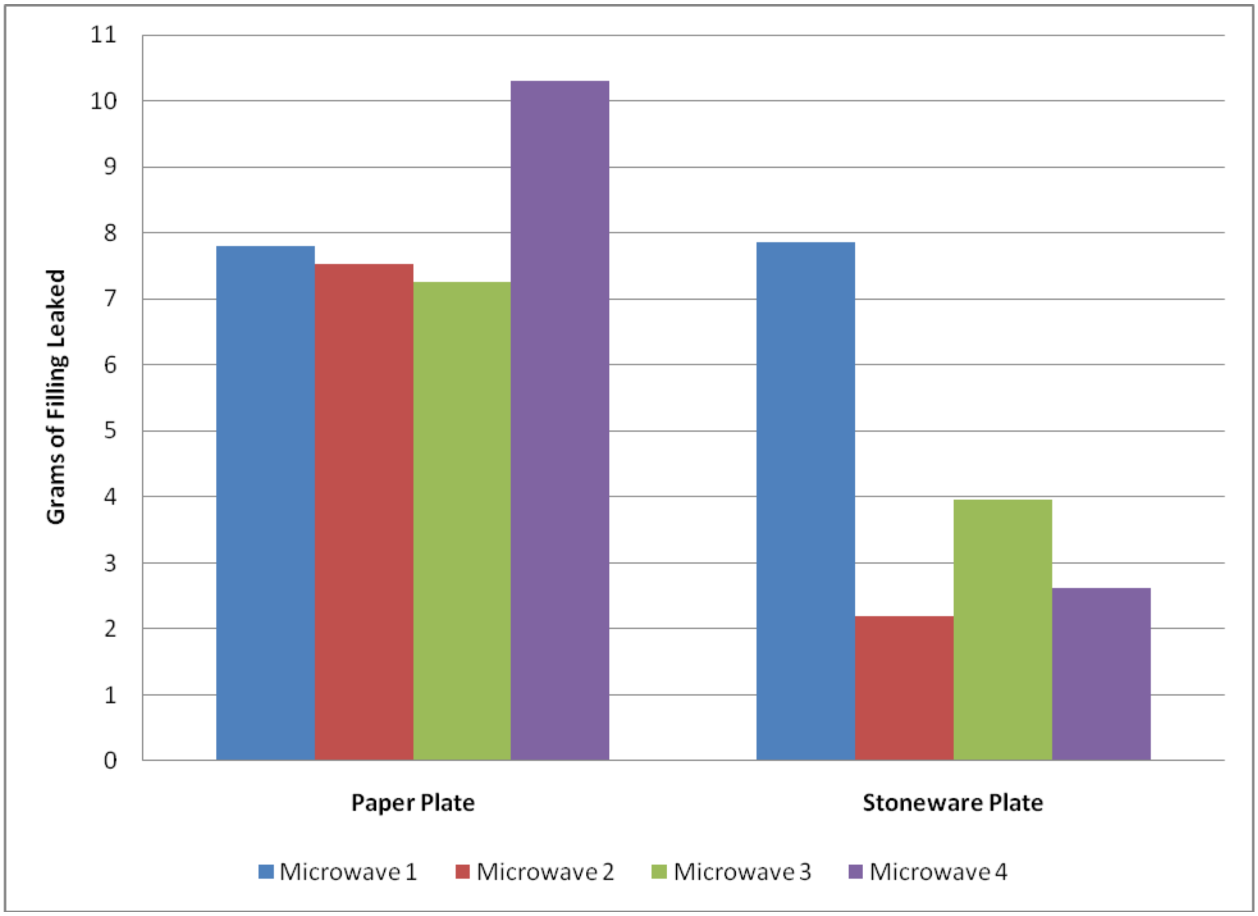

Figure 4-8 – Interaction effect of plate type and microwave on mean grams of filling leaked for calzones in low-watt microwave study.

Grams of Filling Lost Versus Temperature

A fairly strong correlation exists between the grams of filling lost and the average maximum (r=.66) (Figure 4-9) but not between the grams of filling lost and the lowest maximum temperatures (r=.56) (Figure 4-10). There was even less correlation between percent weight loss and average maximum (r=.33) or lowest maximum temperature (r=.18). The Pearson correlation coefficient was used to determine correlation.

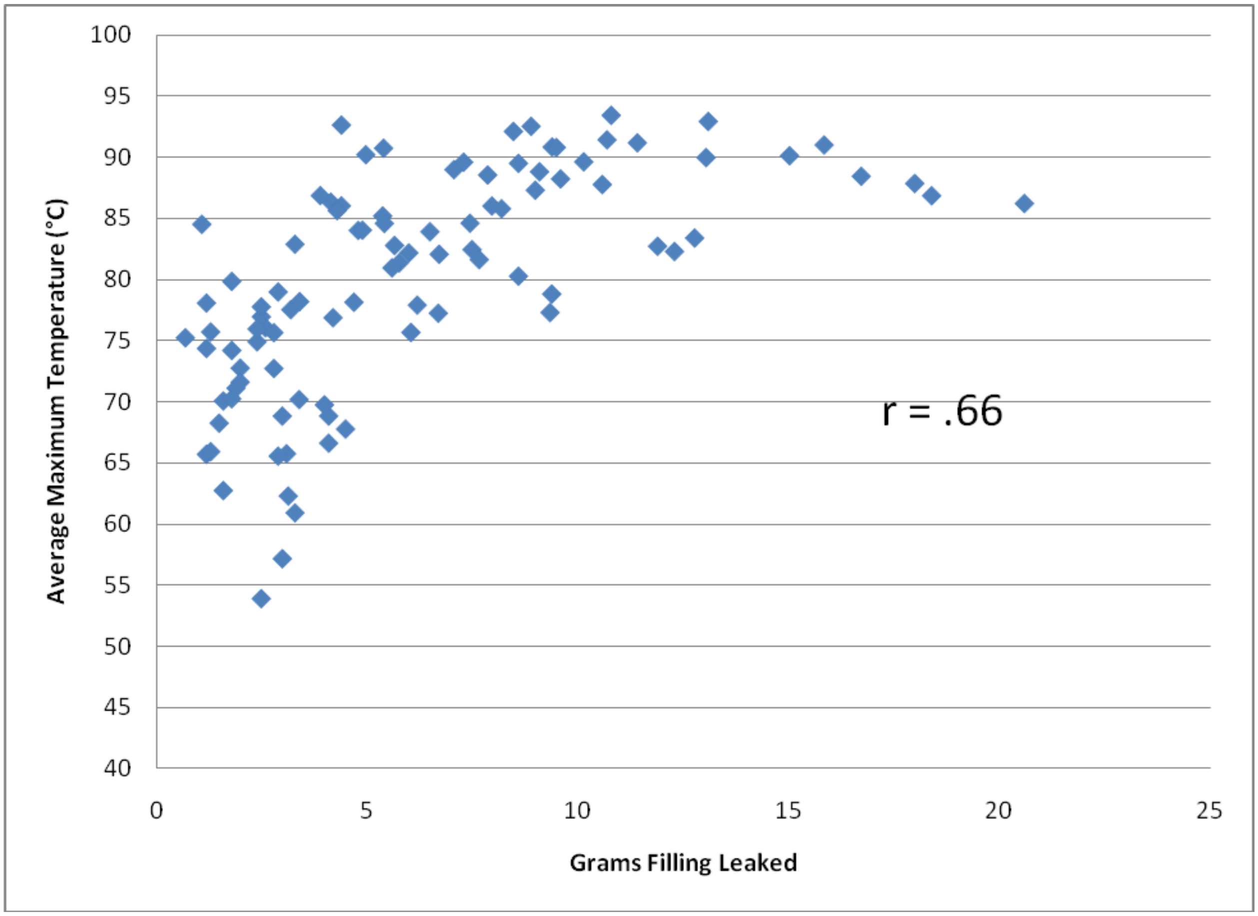

Figure 4-9 – Mean grams of filling leaked versus average maximum temperatures across all plate types, flip steps and microwaves for calzones in low-watt microwave study.

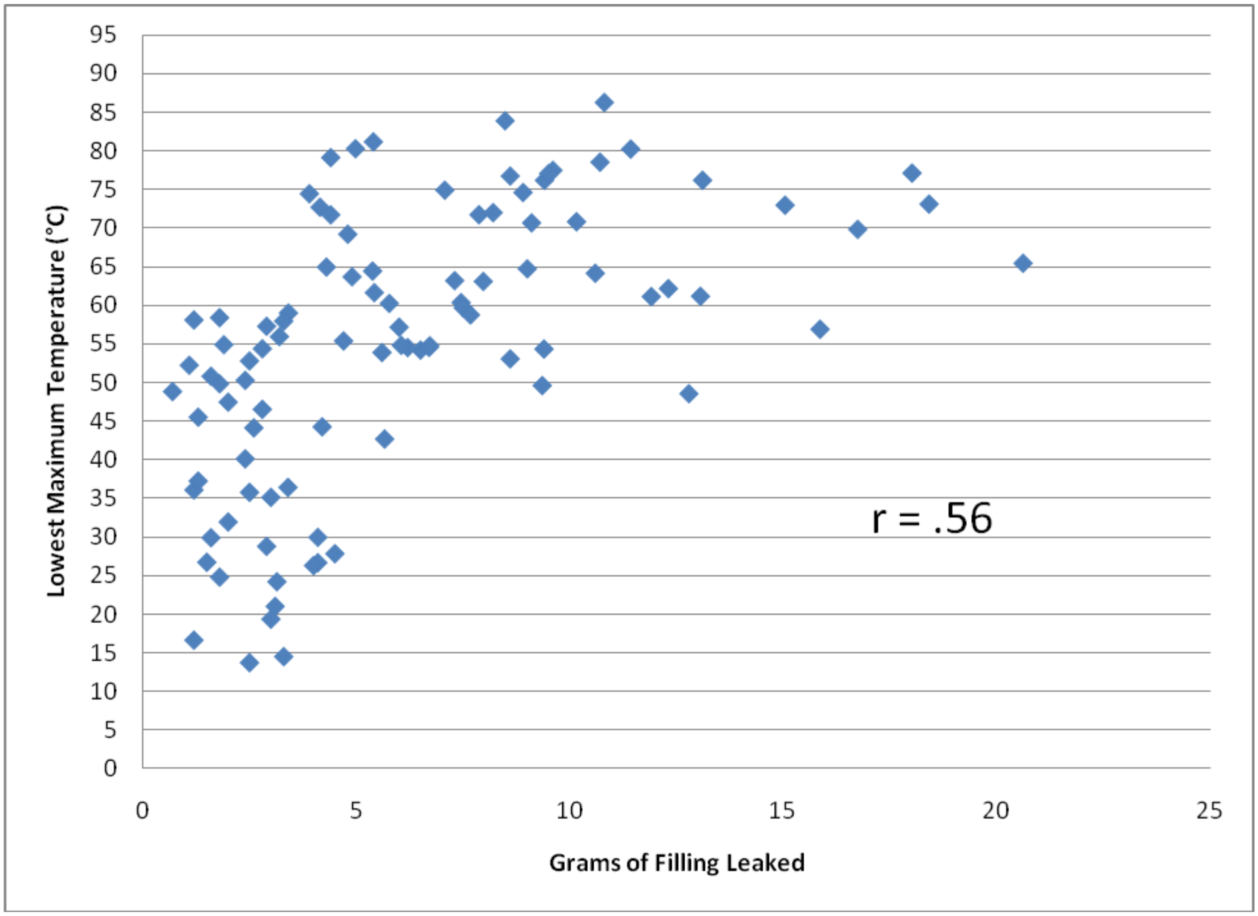

Figure 4-10 –Mean grams of filling leaked versus lowest maximum temperatures across all plate types, flip steps and microwaves for calzones heated in low-watt microwave study.

There seems to be high variability in grams of filling lost which may be a result of seam integrity on the calzone edge as well as increasing temperature of the filling. For the weight loss, the grams of filling leaked were so high in the trial runs that the grams of filling were added back to the calzone weight after heating in order for any reasonable weight loss to be calculated. Thus the percent weight loss was confounded with the grams of leaked filling which does not seem to be wholly related to temperature.

Probe Position and Depth

The 14 probes were categorized according to position and depth. There were six probes on the exterior and eight probes on the interior. The average maximum temperature across the entire study for the exterior probes was 89.9°C and the average maximum for the interior probes was 71.4°C. The probes were also divided into two categories; those above 8mm depth, and those below 8mm depth and analyzed. The average temperature of probes above 8mm depth was 79.2°C and the average temperature of probes below 8mm depth was 80°C. There was no difference in the average temperature of probes that were above or below 8mm, indicating that from top to bottom, temperatures were very uniform on average. This was true even when comparing temperatures of the products that were flipped to product that was not flipped. For the calzones that were flipped, the average upper temperature was 78.5°C and the average lower temperature was 80.4°C and for those that were not flipped, the average temperature was 79.8°C for upper probes and 79.6°C for the lower probes. The difference between upper and lower averages for the flipped calzones was 1.9°C and the difference between the upper and lower for the calzones that were not flipped was .2°C. For this product, the temperatures were uniform from top to bottom, even when the product was not flipped.

Probe position from exterior to interior and from top to bottom was examined but not found to vary greatly from top to bottom; however, the calzone was typically colder on average in the interior than the exterior. This was not universally true. Of the 27 runs that passed killstep, the lowest maximum temperature was recorded in an exterior probe 30% of the time. This finding confirms previous research illustrating that the coldest spot is not always the center in a microwaved product (O'Meara and Reilly 1986; Ryynanen and Ohlsson1996; Goksoy 1999). This indicates the need for placing probes in more than just the interior to ensure the coldest spot is measured. Lowest maximum temperatures in probes only millimeters apart could easily vary 15°C or more indicating the usefulness of as many probes as was practical.

Pass Killstep

For this food system, the pH of the filling was 6.33 and the a_w of the filling was 0.978. The Z-value (13) and the D-value (2.33 s), with a reference temperature of 160°F (71.1°C), were provided by the company from studies they conducted on this food system. Considering manufacturing practices, the killstep goal for this product during the consumer preparation is a 5-log reduction and occurs at 71.1°C instantaneous, or a time/temperature combination that is equivalent to provide a 5-log reduction. If the lowest maximum temperature achieved was 71.1°C, then the run passed killstep. If the lowest maximum was not at or above 71.1°C, the temperature data was analyzed with the AMI Foundation Lethality Spreadsheet to determine if killstep was achieved. There were 22 runs which had a lowest maximum temperature above

71.1°C. There were 20 runs for which the lowest maximum was at least 60°C, but did not achieve 71.1°C and these runs were analyzed. Of these runs, only five of those runs passed the analysis. Table 4-14 shows the lethality for the five runs that didn't hit 71.1°C but passed killstep as calculated with the AMI Foundation spreadsheet. The AMI Foundation Lethality Spreadsheet is attached in Appendix B. Of the five runs that passed additional analysis, there was one run with a lowest maximum of 64.7°C; however, there were two runs with higher lowest maximums that didn't pass upon analysis (Table 4-13). The cells shaded yellow indicate a 5-log reduction and the maximum temperature for each probe is in bold.

The runs that passed killstep were evenly spread across the microwaves and across the two flip methods, but the majority were heated for the highest time (120 seconds) and heated on paper plates (Table 4-12). Of these 27 runs, 13 of them had only one repetition pass. The other 14 runs comprise a set of seven runs where both repetitions passed. In the set of seven runs where both repetitions passed, six of the seven sets were heated on paper plates and five sets were heated for 120 seconds, two for 110 seconds and none for 100 seconds.

Table 4-12 – Percentage of runs that achieved a killstep sorted by microwave, heat time, plate type and flip step.

Microwave	% Passed	Time	% Passed	Plate type	% Passed	Flip	% Passed
1	**30**	100 s	**15**	stoneware	**26**	Yes	**48**
2	**30**	110 s	**39**	paper	**78**	No	**52**
3	**22**	120 s	**56**				
4	**18**						

Of the 13 runs where both repetitions did not pass, the average temperature of the lowest maximum from the repetition that didn't pass was 19°C lower than the average of the repetition that passed. The goal of this study was not to determine the cooking instructions that would provide for killstep as that would limit the ability to distinguish between factors. During heating of high moisture products, a plateau is reached at boiling point and a certain amount of time is spent before enough moisture can be driven off and temperatures can rise again. If all the temperatures were to reach boiling point, and temperatures were only measured post-heating, it would be impossible to tell how long a product had spent at or near the boiling point of water. The times chosen for this study were intended to provide for discernment between factors.

Time to Reach Maximum

The 27 runs which passed killstep were analyzed to determine how many seconds it took for the slowest probe in each run to reach maximum temperature. The average time to reach maximum for the slowest probe in these runs was 40 seconds and the median was 15 seconds. The total range was from five seconds to 120 seconds. Although the average time to reach maximum for the slowest probe in each run was 40 seconds; 33% of the runs had at least one probe which took longer than 1 minute to reach maximum.

Table 4-13 – Lethality calculations for runs with lowest maximum temperatures at or near 64° C.[a]

Lethality calculations for runs with lowest maximum at or near 64 °C						
TIME (sec.)	**RUN 59, Probe 7 (°C)**	**Log reduction**	**RUN 86, Probe 6 (°C)**	**Log reduction**	**RUN 19 Probe 7 (°C)**	**Log reduction**
0	60.17	0.00	51.06	0.00	62.78	0.00
5	62.08	0.09	51.82	0.08	**65.48**	0.25
10	63.15	0.24	53.04	0.17	62.70	0.51
15	63.55	0.42	54.22	0.25	58.76	0.60
20	63.63	0.61	55.34	0.33	57.80	0.64
25	63.73	0.81	56.37	0.42	55.17	0.66
30	63.93	1.03	57.31	0.50	53.25	0.67
35	64.14	1.25	58.13	0.58	52.43	0.67
40	64.30	1.49	58.89	0.67	51.18	0.68
45	64.38	1.74	59.57	0.75	51.44	0.68
50	64.46	1.99	60.14	0.83	52.14	0.69
55	64.56	2.25	60.68	0.92	51.82	0.69
60	64.41	2.51	61.20	1.00	52.46	0.70
65	64.35	2.76	61.66	1.08	52.10	0.70
70	64.41	3.01	62.09	1.17	51.42	0.71
75	64.32	3.26	62.47	1.25	51.30	0.71
80	64.49	3.52	62.83	1.33	52.34	0.72
85	64.73	3.79	63.17	1.42	52.36	0.72
90	64.65	4.06	63.50	1.50	51.70	0.73
95	64.75	4.34	63.80	1.58	51.66	0.73
100	64.73	4.62	64.08	1.67	51.52	0.73
105	64.43	4.89	64.36	1.75	51.18	0.74

110	64.43	5.15	64.61	1.83	50.03	0.74
115	**64.64**	5.41	64.81	1.92	49.80	0.74
120	64.61	5.68	**64.99**	2.00	48.84	0.75

[a] Temperatures in bold are the maximum temperatures, the cells shaded in yellow indicate when a 5 log reduction was achieved.

Table 4-14 – Lethality calculations for runs that passed killstep.

Lethality calculations for passing runs with lowest maximum below 71.1 °C												
TIME (sec.)	**RUN 59, Probe 7 (°C)**	**Log reduction**	**RUN 85, Probe 7 (°C)**	**Log Reduction**	**RUN 85, Probe 8 (°C)**	**Log Reduction**	**RUN 43, Probe 11 (°C)**	**Log Reduction**	**RUN 80, Probe 8 (°C)**	**Log Reduction**	**RUN 46, Probe 12 (°C)**	**Log Reduction**
0	60.17	0.00	69.80	0.00	60.81	0.00	61.40	0.00	60.43	0.00	68.23	0.00
5	62.08	0.09	**70.22**	1.51	61.74	0.09	62.47	0.12	61.92	0.09	70.32	1.26
10	63.15	0.24	70.10	3.10	62.72	0.22	63.31	0.27	63.01	0.23	**70.85**	3.08
15	63.55	0.42	69.84	4.59	63.59	0.39	64.04	0.48	63.96	0.42	70.49	4.95
20	63.63	0.61	69.57	5.96	64.31	0.61	64.76	0.73	64.85	0.68	69.73	6.52
25	63.73	0.81	69.29	7.22	64.91	0.89	65.41	1.05	65.64	1.01	68.81	7.73
30	63.93	1.03	69.11	8.39	65.38	1.21	65.87	1.42	66.28	1.43	68.06	8.65
35	64.14	1.25	68.91	9.49	65.80	1.58	66.45	1.87	66.79	1.93	67.10	9.36
40	64.30	1.49	68.79	10.53	66.25	2.00	66.89	2.39	67.21	2.51	66.84	9.93
45	64.38	1.74	68.65	11.53	66.67	2.49	67.26	2.98	67.58	3.17	67.10	10.50
50	64.46	1.99	68.53	12.50	67.04	3.04	67.58	3.65	67.88	3.90	66.12	11.02
55	64.56	2.25	68.43	13.42	67.34	3.66	67.84	4.37	68.24	4.71	65.25	11.40
60	64.41	2.51	68.35	14.33	67.63	4.34	68.10	5.16	68.54	5.61	64.24	11.69
65	64.35	2.76	68.29	15.21	67.92	5.08	68.44	6.03	68.83	6.60	63.71	11.91
70	64.41	3.01	68.25	16.08	68.13	5.88	68.59	6.97	69.05	7.68	63.25	12.10
75	64.32	3.26	68.21	16.93	68.33	6.74	68.71	7.95	69.31	8.84	63.43	12.28
80	64.49	3.52	68.17	17.78	68.51	7.65	68.87	8.97	69.50	10.08	62.62	12.44
85	64.73	3.79	68.17	18.62	68.69	8.61	69.05	10.05	69.68	11.41	62.74	12.59
90	64.65	4.06	68.19	19.46	68.84	9.63	69.24	11.20	69.84	12.80	62.17	12.73
95	64.75	4.34	68.19	20.31	68.96	10.69	69.37	12.41	69.98	14.27	61.80	12.84
100	64.73	4.62	68.13	21.15	69.08	11.79	69.49	13.66	70.12	15.80	61.50	12.95
105	64.43	4.89	68.11	21.97	69.18	12.94	69.59	14.96	70.32	17.41	61.45	13.05
110	64.43	5.15	68.07	22.79	**69.24**	14.11	69.67	16.30	70.46	19.12	60.69	13.14
115	**64.64**	5.41	52.37	23.20	48.83	14.70	69.75	17.67	70.56	20.89	60.33	13.21
120	64.61	5.68	Probe Apparatus removed early/no data				**69.87**	19.09	**70.71**	22.73	60.34	13.28

Conclusions

All of the factors studied had significant effects on heating of calzones in the low-watt microwaves, with the exception of flip step.

Plate type appears critical to heating the calzone in these microwaves and various plate types should be tested when developing instructions for NRTE products. Stoneware plates should be preferentially chosen as the test plate for safety reasons. Multiple microwaves in each wattage range should be tested when developing directions for NRTE products because wattage alone cannot predict performance. A follow-up experiment should be conducted to determine if it was the physical flipping of the calzone or the stopping of the microwave that influences heating by comparing a product that is stopped and flipped to a product that is heated without stopping or flipping. The presence of interactions between microwaves and plate type further stresses the need to test multiple microwaves and plate types in cooking instruction validation testing. The three-way interaction illustrates that products prepared in each microwave performed very differently depending on the flip and plate factors. Design elements of the microwaves may play a role; however, these design elements are invisible to the consumer and unpredictable.

In using the results of this experiment to design validation testing for calzones, it is recommended that testing be done in multiple microwaves even within a wattage range since significant differences were observed among microwaves with the same or similar stated wattage.

If the cooking instructions are to include a recommendation to "heat further if not hot enough", the time interval suggested should be greater than 10 seconds.

Neither the grams of filling lost nor the percent weight loss appear to have been reliable predictors of temperature. The correlation coefficients were all below .6 which would not be strong enough to rely on for food safety. Testing only the interior of the sample is not recommended since the exterior could sometimes record the coldest temperature. Runs that passed killstep were not always repeatable indicating that the times tested were not sufficient to achieve killstep to the degree necessary for food safety. Additional heating time is warranted.

Because 33% of the runs that passed killstep did not achieve their lowest maximum temperature within 60s, instructing consumers to let the product stand for 1 minute after heating would not be sufficient for food safety in all cases. If a 1 minute stand time is desired, additional time would be required in the heating step.

Although the flip step as tested in this experiment didn't affect heating, a follow-up study should be conducted to examine whether the flip step or the stopping of the microwave midway through heating was the true influencing factor. This full experiment should also be executed in higher wattage microwaves to determine if the factors are still as influential on heating.

In many cases significant differences were observed in standard deviation of maximum temperatures. In all cases, the higher the temperatures recorded, the lower the standard deviations. This does not seem to be a result of better uniformity from 1 level of a factor to another, but rather a side effect of temperatures approaching the boiling point where a temporary ceiling was reached on temperature. If the validation testing protocol is developed to favor food safety conditions it may be necessary to include a test cell which represents a check for quality. For instance, a test cell in a cold microwave using paper plates should heat far beyond killstep when following the cooking instructions developed for food safety.

CHAPTER 5 - Flip Step Test

Abstract

In the previous experiment described in Chapter 5, the act of flipping a calzone over mid-way through the heating process in a microwave was shown to have no effect on the temperature. The experiment tested two conditions; stopping the heating process and flipping versus stopping the heating process and not flipping. It is important to understand what will happen if consumers skip the flip step altogether and do not stop the heating process. A 2x3 experiment in quadruplicate was executed. The factors were flip method and microwave oven. For the flip method, the calzone was heated for 1 minute on high, the product was flipped over and then further heated on high for 50 seconds. For the no-flip method, the calzone was heated on high for a full 1 minute 50 seconds without stopping. All calzones were heated on paper plates in pre-heated microwaves. Power to the microwave was held constant at 120 V. Calzones were held at -17.8°C. Fourteen temperatures probes attached to a plate were lowered onto the calzone within 30 seconds of heating. Temperatures were recorded every five seconds over a period of 2 minutes post-heating. The data was analyzed by ANOVA and significant differences were compared using Tukey means. Calzones that were flipped had significantly higher average maximum temperatures ($p<.05$). No significant differences were observed in standard deviation, lowest maximum, or grams of filling lost. A significant interaction effect ($p<.05$) was observed for average maximum between the flip method and the microwave. The average temperature when the calzone was heated in microwaves 1 and 3 were similar; however, not flipping the calzone in microwave 2 resulted in significantly lower average temperatures (91.2°C versus 82.3°C). The evidence from the previous experiment indicated that there was no significant difference between stopping and flipping and stopping and not flipping. A study cannot be executed where a flip step is employed without stopping the microwave. These two studies combined indicate that it is the stopping of the microwave that is likely to be a factor influencing the heating in some microwaves as opposed to the act of flipping the calzone.

Introduction

A previous experiment described in Chapter 5 which studied factors affecting heating of calzones in microwave ovens focused on four factors; microwave, heat time, flip step and plate material on which the calzone was heated. The act of flipping a calzone over mid-way through heating was shown to have no effect on the temperature. This previous experiment however tested two conditions, stopping the heating process and flipping versus stopping the heating process and not flipping.

From the standpoint of ensuring that consumers achieve a killstep when heating the calzone in the microwave, it is important to understand what will happen if consumers skip the flip step altogether. If they do, it is unlikely they will stop the heating process at all. Therefore, it is important to test whether the stopping of the microwave has any effect on the heating to determine how critical the flip step is to heating.

Materials and Methods

A 2x3 experiment in quadruplicate was executed with a total of 24 runs. The factors were flip step and microwave oven. The heat time was set at 110 seconds which was the mid-point of heating time in the previous study and the plates used were paper plates. In the previous test, the flip method did not affect heating on paper plates or stoneware plates. In order to reduce the total number of runs and conserve product, only paper plates were chosen for testing. All of the microwaves were pre-heated for ten minutes following the procedures outlined in Chapter 5. The order of runs for each session was randomized within each microwave and across the sessions. Power to the microwave was controlled with a Powerstat 3PN136B (The Superior Electric Company, Bristol, CN., U.S.A.) and held constant at 120V once the magnetron had started. Calzones were held at -17.8°C. The data was analyzed by ANOVA and significant differences were compared using Tukey means.

Factors

Microwave Ovens

The three microwave ovens chosen represent typical consumer microwaves sold in the U.S. over the past seven years in the lowest wattage range and comprise three of the four microwaves used in the Chapter 5 study (Table 5-1).

Table 5-1 – Brand, wattage, age and dimensions of microwave ovens used in the flip step testing.

Unit	Manufacturer	Stated wattage	Age (yrs)	Measured output wattage (IEC 60705)	Ht (inches)	Width (inches)	Depth (inches)	Volume (cubic feet)
1	Amana Radarange	800	7	700	7.8	11.8	11.3	0.6
2	GE	700	1	550	7.1	11.5	10.0	0.5
3	Sharp Carousel	800	4	650	7.4	11.9	12.1	0.8

Flip Step

The cooking instructions direct the consumer to flip the product over in step 3 after 1 minute of heating. For the flip treatment, the calzone was heated for 1 minute on high, the door was then opened, the product was flipped at this point and the product was then further heated on high for 50 seconds. For the no flip treatment, the calzone was heated on high for a full 1 minute 50 seconds (110 s) continuously.

Data Collection

The data collection methods utilized in Chapter 5 were employed for this experiment without exceptions.

Responses

For each run, immediately after heating (<30 seconds), the calzone was removed and the apparatus was placed on top of the calzone. The exact placement of the apparatus was guided by markings on each plate made with a template to match the position of the calzone and legs of the probe apparatus. Temperatures of each probe were measured every 5 seconds over a period of 2 minutes post-heating in the microwave using the probe apparatus and the data was recorded using a data logger. The responses measured are listed in Table 5-2.

Table 5-2 – Responses measured and how the responses were obtained for the flip step test.

Responses	How obtained
Average Maximum	Maximum temperature recorded across the 14 probes during the 2 minutes post-heating
Standard Deviation among Maximums	Standard deviation of the maximums recorded for each run
Lowest Maximum	Lowest maximum recorded from the 14 maximums from each run (indicative of whether killstep was achieved)
Grams of Filling Leaked	Measured in grams by weighing the plate before and after heating to measure the grams of filling that leaked onto the plates during heating.

Results and Discussion

Microwave

No significant differences were found in the average maximum, standard deviation, lowest maximum, or grams of filling lost among the 3 microwaves (Table 5-4). The significant differences observed between these microwaves in the first study pay have been influenced by the stoneware plates. Heating on paper plates throughout this test resulted in more consistent heating from one microwave to the next.

Table 5-3 – Mean values for average maximum temperature, standard deviation between maximums, lowest maximum temperature and grams of filling lost for calzones in the flip method test heated in three low-watt microwaves. [a]

Microwave	Average maximum temperature (°C)	Standard deviation among maximums	Lowest maximum temperature (°C)	Grams of filling lost
1. Amana Radarange	87.4[a]	10.7[a]	66.4[a]	8.5[a]
2. GE	86.7[a]	9.3[a]	68.1[a]	5.2[a]
3. Sharp Carousel	89.4[a]	8.0[a]	74.0[a]	7.8[a]

[a] Means with different letters in columns are different ($p<0.05$).

Flip Step

There were significant differences found in the average maximum ($p<.05$) between the two flip methods. The average maximum temperature of calzones that were stopped and flipped was 89.2°C compared to calzones heated without stopping and flipping which was 86.4°C (Table 5-3). No significant differences were observed in standard deviation, lowest maximum, or grams of filling lost (Table 5-3).

Table 5-4 – Mean values for average maximum temperature, standard deviation between maximums, lowest maximum temperature and grams of filling lost for calzones flipped and not flipped in the flip method test. [a]

Flip Method	Average maximum temperature (°C)	Standard deviation among maximums	Lowest maximum temperature (°C)	Grams of filling lost
Yes	89.2[a]	10.3[a]	71.0[a]	8.2[a]
No	86.4[b]	8.7[a]	68.0[a]	6.1[a]

[a] Means with different letters in columns are different ($p<0.05$).

Overall, the difference between stopping and flipping versus not stopping and not flipping was not large. The significant interaction between the microwave and the flip method may explain this.

Interaction

A significant interaction effect ($p<.05$) was observed for average maximum temperature between the flip method and the microwave (Figure 5-1). The average temperature when the calzone was heated in microwaves 1 and 3 were similar; however, not flipping the calzone in microwave 2 resulted in significantly lower average temperatures. This is not predictable but is critical when understanding whether the flip step should be employed. Although in most cases it doesn't appear to affect heating, the observation of one microwave where it is critical is enough to warrant the inclusion of a flip step when heating this product in all microwaves. It cannot be predicted in what type of microwave you may or may not need to flip the product. Because the difference in temperature between the two flip methods in microwave 2 is so large, it may be advised to stress the importance of this step to the consumer in the package directions.

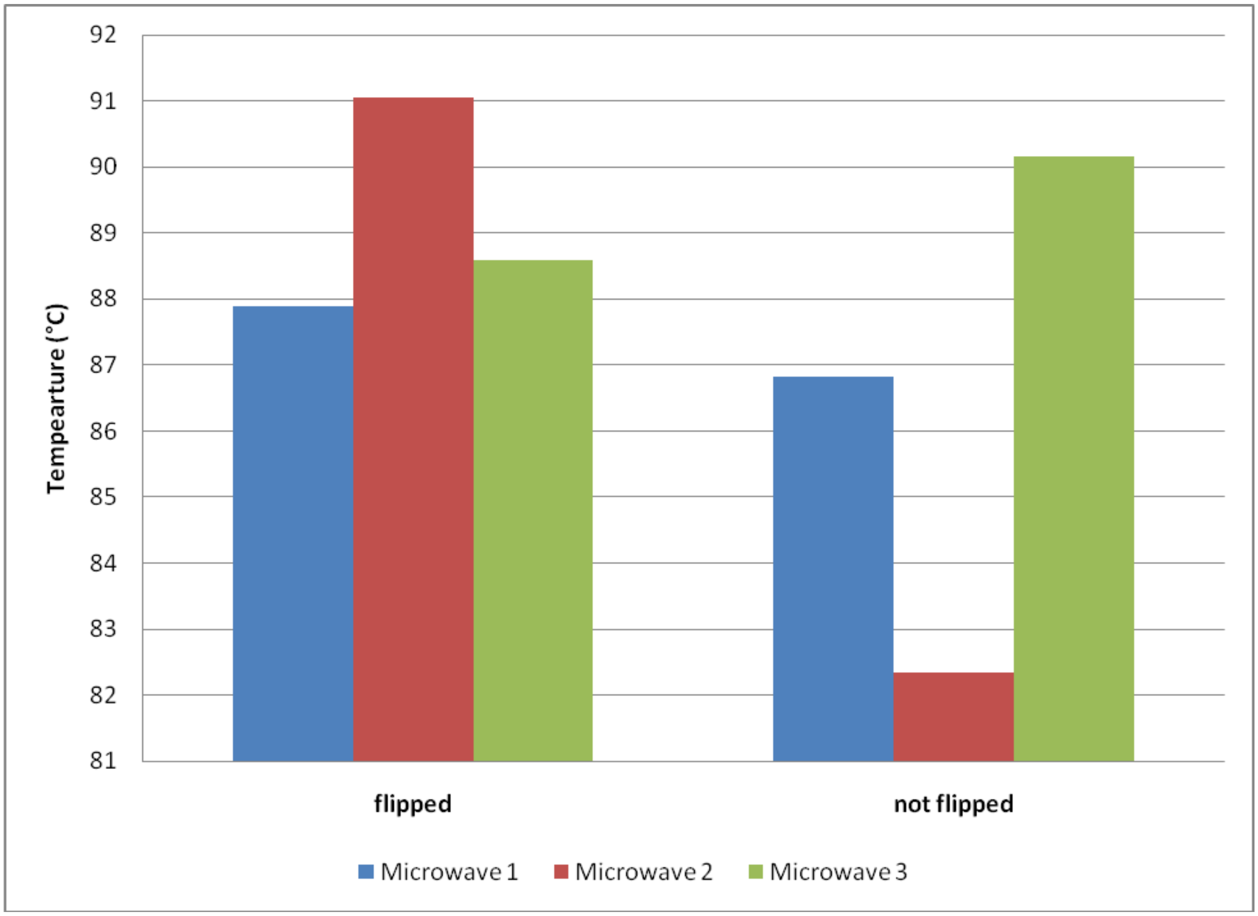

Figure 5-1 – Interaction effect of flip step and microwave on average maximum temperatures of calzones heated in the flip method test.

Conclusions

In this experiment, stopping the microwave and flipping the calzone produced a significantly higher average temperature compared to not stopping and flipping the calzone. This appears to be due to the very low temperatures observed in microwave 2 when the product was not flipped. Although there were differences in the average maximum, significant differences were not found in the lowest maximum. The evidence from the previous experiment indicated that there was no significant difference between stopping and flipping and stopping and not flipping. A study cannot be executed where a flip step is employed without stopping the microwave. Based on the results from these 2 studies, it is recommended that further testing be executed by stopping and flipping the calzone mid-way through heating for all runs. This step should also be included in any consumer preparation directions since the possibility of under-heating exists of the heating is not stopped and the product flipped in some microwaves.

CHAPTER 6 - Follow-Up Study at Higher Wattages

Abstract

An understanding of the factors that may affect a consumer's ability to achieve a killstep when cooking microwavable not-ready-to-eat foods is critical to determining the optimum cooking instructions for food safety. Factors are often studied in isolation or within a single microwave. The least-studied factors appear to be those that are controlled by the consumer. Consumer-driven factors such as microwave appliance, heat time, and plate material were studied to determine their effect on final temperature of a frozen hand-held calzone sandwich after heating. The calzone was heated on a plate for 1 minute, then flipped and heated again for the remaining time in each of four higher wattage microwave ovens. A full-factorial experimental design (4x3x2) was executed in duplicate. Fourteen hypodermic needle probes were attached to a data logger and temperatures were recorded every 5 seconds for 2 minutes post-heating to attain the average maximum temperature and lowest maximum temperature for each run. The data was evaluated by analysis of variance and significant differences were compared using Tukey means. Microwave appliance and heat time had significant effects on temperature. Plate type was not a significant factor. The effect of plate type was dependent on the exact microwave used. Multiple microwaves in this wattage range should be used for development because wattage alone cannot predict performance and because of the interaction between microwave and plate type.

Introduction

Background

This experiment was a follow-up study to the experiments described in Chapters 5 and 6. The previous experiments found that plate type, appliance, and heat time had significant effects on the heating of calzone in lower wattage microwaves. The flip step resulted in significantly higher average temperatures when compared to calzones which were heated without stopping, but not when compared to calzones heated with a stop that didn't include a flip. This indicated that it was the process of stopping the microwave which was critical. It is unlikely; however, that consumers will stop a microwave without flipping, so it was recommended that the directions be further tested utilizing a flip step. This final experiment was designed to understand how these same consumer-driven factors (appliance, heat time and plate type) affect heating of a food in higher wattage microwaves. Understanding the impact of these factors is critical to developing a validation program for consumer instructions.

Objectives

This research aims to understand the impact of several consumer-driven factors on heating of a calzone in the microwave. These factors include plate material, heat time and microwave appliance. These consumer-driven factors are some of the least studied among the factors affecting heating rates for microwave products. Previous testing has been generally limited to 1 microwave; however, this research will test the effect of factors across a wide range of microwaves which is a far better predictor of what will happen in consumers' homes. It is hypothesized that while many factors affect heating rate, most are minimal in comparison to the differences between microwaves even within a wattage category. An understanding of the relative importance of certain factors would allow for the creation of optimized testing protocol. This information will be valuable to anyone engaged in testing and validating cooking instructions.

Materials and Methods

Product

The frozen NRTE hand-held calzone sandwich consisted of an outer crust of bread and an interior pizza filling with sauce, cheese, and meat components. The product was supplied by General Mills, Canada Corporation, Toronto, CAN. The ingredients were: enriched wheat flour, water, pizza topping (water, palm oil, rennet casein, modified potato starch, salt, milk ingredient, sodium phosphate, sodium aluminum phosphate, lactic acid, sorbic acid, colour[contains modified coconut oil], flavour), cooked pepperoni and bacon, canola oil, tomato paste, salt, sugar, baking powder, modified corn starch, monoglycerides, whey powder, garlic and onion powder, flavour, spice, xanthan gum, soybean oil, l-cysteine hydrochloride. The calzones were approximately 2.3 cm thick, 11.5 cm long and 6.3 cm wide. The shape was a half-circle. The average weight was 104g and the dough to filling ratio by weight was approximately 40:60. The product was stored at -17.78°C.

The cooking instructions were:

5. Place on microwave-safe plate.
6. Microwave on HIGH for 1 minute.
7. FLIP product over and microwave additional 15 to 30 seconds.
8. Let stand 1 minute.

The product was stored at -17.78 °C. This temperature was at or colder than 83% of home freezers according to the EcoSure 2007 U.S. Temperature Evaluation study.

Experimental Design

The experimental set-up was a full factorial design with three factors. There were four microwaves, three heat times, and two plate materials. This resulted in a 4x3x2 design with 24 microwave runs. Each run was performed in two replications for a total of 48 runs. The design was executed in three separate sessions of 16 runs; with four runs per microwave in each session. For each microwave a pre-heat step was employed followed by four test runs. There was a minimum rest period of five hours between each session. The pre-heat step allowed for multiple runs to be performed in a period of stable output wattage without a rest period between runs. The testing to establish the validity of this pre-heat step is documented in Chapter 3. The order of runs for each session was randomized within each microwave and across the sessions. Power to the microwave was controlled with a Powerstat 3PN136B (The Superior Electric Company, Bristol, CN. USA) and held constant at 120 V once the magnetron had started.

Factors

Microwave Ovens

The 4 microwave ovens chosen for this study represent typical consumer microwaves sold in the U.S. over the past 7 years in the highest wattage range (Table 6-1). The microwave output wattage was measured using the IEC 60705 (Ed. 3.2, 2006) one-liter water test.

Table 6-1 – Brand, model number, wattage, age, and dimensions of microwave ovens used in the high-watt microwave test.

Unit	Manufacturer	Stated wattage	Age (yrs)	Measured output wattage (IEC 60705)	Ht (inches)	Width (inches)	Depth (inches)	Volume (cubic feet)
5	Whirlpool	1100	7	1000	8.5	14.5	14.5	1.0
6	Sharp Carousel	1200	7	1100	9	12.75	13.25	.88
7	Goldstar	1000	5	950	8.5	12.75	13.25	.83
8	Samsung	1000	6	950	10.25	13.25	13	1.0

Microwaveable Plate

The plates were chosen from a set of typical consumer plates available at retail at the time of the study. An initial test with pizza snacks and pizza calzones were used to narrow down the plate type options to 2. The initial plate tests are described in Chapter 2. The 2 treatments for this factor were a paper plate, 9” diameter, Basicware™ brand uncoated paper plate, (Target Corp. Minneapolis, MN, USA), and a 10” diameter, Room Essentials ™ brand diameter stoneware plates, (Target Corp. Minneapolis, MN, USA). The average weight of the paper plate was 6.8g and the stoneware plate was 602.9g.

Time

The time range used in this study was pre-determined by test runs in these microwaves which identified the approximate time that would approach killstep but not overheat the product and destroy the quality. The three times chosen for this wattage range were 80 seconds, 90 seconds and 100 seconds. For each run, sixty seconds was entered into the control panel of the microwave and the start button was pushed. After sixty seconds, the door was opened and the calzone was flipped over. The door was shut and the calzone was then heated on high for the remainder of the time appropriate to the run (20 seconds for an 80 second run, 30 seconds for a 90 second run and 40 seconds for a 100 second run).

Data Collection

Data collection was identical to the methods employed in Chapter 5. The steps for gathering the data are listed below:

1. Microwave is pre-heated using 1,000g of 4°C water in glass bowl on high for 10 minutes.
2. Sides of microwave are wiped down and turntable is cooled to room temperature in a water bath.
3. Calzone is removed from -17°C storage and placed on room temperature plate.
4. Plate and calzone are weighed.
5. Plate and calzone are placed in center of microwave turntable and heated on high for 1 minute.
6. Door is opened; calzone is flipped, or not flipped, and heated for remainder of time appropriate to that run.
7. Temperature probe apparatus is placed on top of calzone and temperatures are recorded every 5 seconds for 2 minutes post-heating.
8. Calzone is weighed.
9. Plate is weighed and difference from initial weight is recorded as grams of filling leaked.

Responses

For each run, immediately after heating (<30 s), the calzone was removed and the apparatus was placed on top of the calzone. The exact placement of the apparatus was guided by markings on each plate made with a template to match the position of the calzone and legs of the probe apparatus. Temperatures of each probe were measured every 5 seconds over a period of 2 minutes post-heating in the microwave using the probe apparatus. This method allowed for the determination of the maximum temperature achieved in each probe during the 2 minutes post-heating. Grams of filling lost and percent weight loss were tracked in order to determine if they would be good predictors of temperature. The grams of filling lost were calculated by weighing the amount of filling that leaked onto the plate after heating. In order to calculate percent weight loss, the final weight of the calzone after heating consisted of the weight of the heated calzone plus the grams of filling that leaked onto the plate. Time to reach maximum temperature was recorded to determine how long the stand time should be post-heating for food safety. Probe position was tracked in order to determine if any of the variables had an effect on uniformity. The responses measured are listed in Table 4-3.

Data Analysis

Analysis of Variance (ANOVA) was performed on the data to determine the effect of the factors using SAS® 9.1 (SAS Institute Inc., Cary, NC, USA). Each factor was tested against these responses and significant differences were noted. When significant differences were detected, Tukey's Standardized Range test (HSD) ($\alpha = 0.05$) was used to determine which levels of the factor were different from each other. The weight of each calzone was recorded and was included as a covariate in the GLM model for increased precision in determining the effect of the factors on the responses.

Results and Discussion

Microwave Oven

There were significant differences found in average maximum ($p<.05$), standard deviation of maximums ($p<.05$), and lowest maximum ($p<.05$), among the four microwave ovens. Calzones heated in microwave 6 had significantly higher average maximums and lowest maximum temperatures and significantly lower standard deviations than all other microwaves. The stated wattage of this microwave was the highest in the set. Calzones heated in microwaves 5, 7, and 8 were not significantly different from each other on any of the temperature measurements (Table 6-2).

Table 6-2 – Mean values for average maximum temperatures, standard deviation among maximum temperatures, lowest maximum temperature and measured wattage output of calzones in four high-watt microwaves. [a]

Microwave	Average maximum temperature (°C)	Standard deviation among maximums	Lowest maximum temperature (°C)	Measured wattage output (IEC 60705)

6 – Sharp Carousel	87.0[a]	8.4[a]	71.7[a]	1100
5 – Whirlpool	82.9[b]	13.4[b]	59.8[b]	1000
7 – Goldstar	82.0[b]	12.8[b]	57.9[b]	950
8 – Samsung	79.7[b]	12.5[b]	59.5[b]	950

[a] Means with different letters in columns are different (p<0.05).

There were significant differences found in grams of filling leakage (p<.05) and percent weight loss (p<.05) among calzones heated in the four microwave ovens. Calzones heated in microwaves 6 and 7 lost significantly more grams of filling than calzones heated in microwaves 5 and 8 (Table 6-5). There was less differentiation among the microwaves in percent weight loss.

Table 6-3 – Mean grams of filling leaked and mean percent weight loss for calzones heated in four high-wattage microwaves. [a]

Microwave	Grams of Filling Leaked	Percent Weight loss
6 – Sharp Carousel	12.0[a]	7.2[b]
7 – Goldstar	11.1[a]	6.8[bc]
5 – Whirlpool	5.9[b]	9.1[a]
8 – Samsung	4.8[b]	6.1[c]

[a] Means with different letters in columns are different (p<0.05).

Calzones heated in the 1200-watt microwave (stated wattage), were significantly hotter than calzones heated in the 1100 watt or either of the 1000 watt microwaves which were not significantly different from each other. Because the wattage test itself was understood to be highly variable and results were rounded to the nearest 50 watts, it was unlikely that the differences noted between microwaves within a range of 100 watts were strictly due to the wattage. In the Chapter 5 test with lower wattages, a wattage difference of 150 was not significant. Multiple microwaves in each wattage range should be tested when developing directions for NRTE products.

The lack of correlation between grams of filling lost, percent weight loss and average or lowest maximum temperatures is thought to be the result of poor seam integrity.

Heat Time

There were significant differences found in average maximum (p<.05), standard deviation of maximums (p<.05), and lowest maximum (p<.05), among the three heat times tested. Calzones heated for 100 seconds had significantly higher average maximums and lowest maximums and significantly lower standard deviation of the maximums compared to calzones heated for 90 seconds or 80 seconds. Temperatures of calzones heated for 90 seconds or 80 seconds were not significantly different from each other (Table 6-4).

Table 6-4 – Mean values for average maximum temperature, standard deviation among maximums, and lowest maximum temperature for calzones heated in high-watt microwaves for 100, 90, and 80 seconds. [a]

Time	Average maximum temperature (°C)	Standard deviation among maximums	Lowest maximum temperature (°C)
100 s	87.0[a]	9.6[a]	68.7[a]
90 s	82.1[b]	12.0[b]	60.6[b]
80 s	79.6[b]	13.7[b]	57.3[b]

[a] Means with different letters in columns are different ($p<0.05$).

There were significant differences found in grams of filling leaked ($p<.05$), and percent weight loss ($p<.05$), among the three heat times tested. Calzones heated for 100 seconds had significantly higher grams of leaked filling than those heated for only 90 seconds or for 80 seconds. Increasing the heat time from 80 seconds to 90 seconds led to significantly higher percent weight loss, as did increasing the heat time from 90 seconds to 100 seconds (Table 6-5).

Table 6-5 – Mean grams of filling leaked and mean percent weight loss for calzones heated in high-watt microwaves for 100, 90, and 80 seconds. [a]

Time	Grams of Filling Leaked	Percent Weight Loss
100 s	11.3[a]	9.9[a]
90 s	7.9[b]	7.0[b]
80 s	6.1[b]	5.0[c]

[a] Means with different letters in columns are different ($p<0.05$).

Longer heat times produced higher temperatures, higher percent weight loss and more grams of filling leaked. Differences of 10 seconds of heating were significant only when moving from 90 seconds to 100 seconds. While in this instance, the temperatures and grams of filling lost are related, it may be that longer heating times allowed for more filling to leak out. Given the data on microwaves, where temperature and leakage were not correlated, it isn't likely the higher temperatures that resulted from the longer heating is necessarily what caused the higher leaking.

. These findings were the same as for the lower wattage microwaves studied in Chapter 5. In some cases, an additional 10 seconds was not enough to significantly raise the temperature of the calzone. If the consumer is instructed to add additional time, it should be in increments greater than 10 seconds.

Plate Type

There were no significant differences found in average maximum ($p>.05$), standard deviation of maximums ($p>.05$), and lowest maximum temperatures ($p>.05$) of calzones heated on the two plates types (Table 6-6).

Table 6-6 – Mean values for average maximum temperature, standard deviation among maximums, and lowest maximum temperature for calzones heated in high-watt microwaves on paper and stoneware plates. [a]

Plate Type	Average maximum temperature (°C)	Standard deviation among maximums	Lowest maximum temperature (°C)
Paper	83.4[a]	12.0[a]	62.5[a]
Stoneware	82.3[a]	11.5[a]	61.9[a]

[a] Means with different letters in columns are different ($p<0.05$).

No significant differences were found in grams of filling leaked ($p>.05$) between calzones heated on the 2 plate types. Significant differences in percent weight loss ($p>.05$) of calzones heated on paper versus stoneware plates were observed. Calzones heated on paper plates had significantly higher weight loss, 8.17%, versus those heated on stoneware plates which lost an average of 6.46% (Table 6-7).

Table 6-7 – Mean grams of filling leaked and mean percent weight loss for calzones heated in high-watt microwaves on paper and stoneware plates. [a]

Plate Type	Grams of Filling Leaked	Percent Weight Loss
Paper	9.0[a]	8.2[a]
Stoneware	7.9[a]	6.5[b]

[a] Means with different letters in columns are different ($p<0.05$).

Of all the factors tested in this high wattage microwave study, plate type had the least effect on calzone temperature. A significant difference only existed in percent weight loss, with the calzones heated on paper plates having significantly more weight loss. This was the opposite finding as in the lower wattage study in Chapter 5, where plate type had the largest effect. The larger microwaves are designed to hold larger loads and therefore may be less affected by the presence of stoneware plates compared to the smaller microwaves. Although overall the plate type doesn't have an effect, the interaction that was observed indicates that plate type can be critical in some higher wattage microwaves.

Interactions

Significant interactions were detected between the microwave and plate type in average maximum ($p<.05$), standard deviation of maximums ($p<.05$), and lowest maximum ($p<.05$). For microwave 5, there was a large difference between the average maximum, (Figure 6-1) standard deviation (Figure 6-2) and lowest maximum (Figure 6-3) when heated on a paper plate or a stoneware plate whereas for the other microwaves, the difference was much smaller and in the opposite direction. For the lowest maximum, a three-way interaction was also found to be significant between microwave, flip step and plate type ($p<.05$).

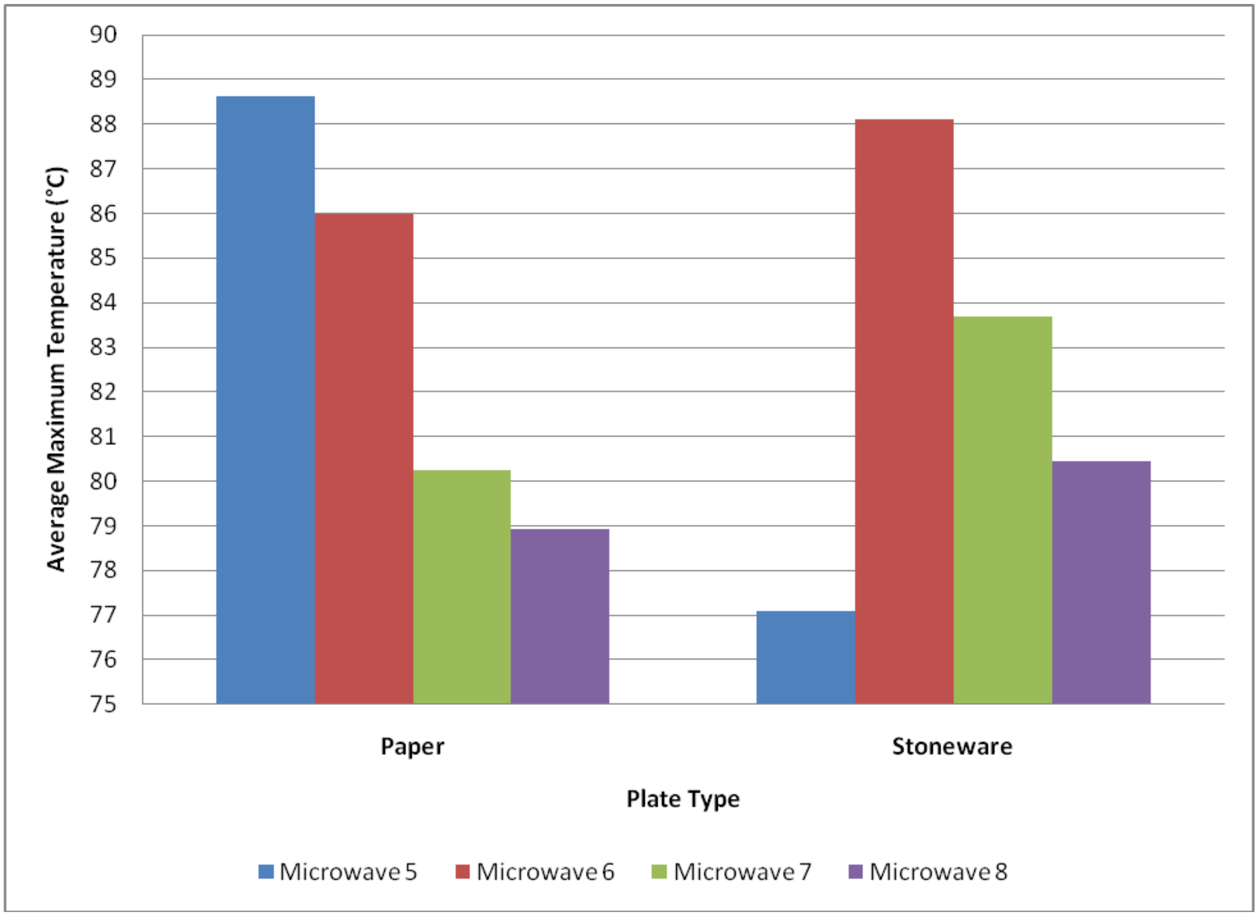

Figure 6-1 – Interaction effect between microwave and plate type on average maximum temperatures of calzones in high-watt microwave study.

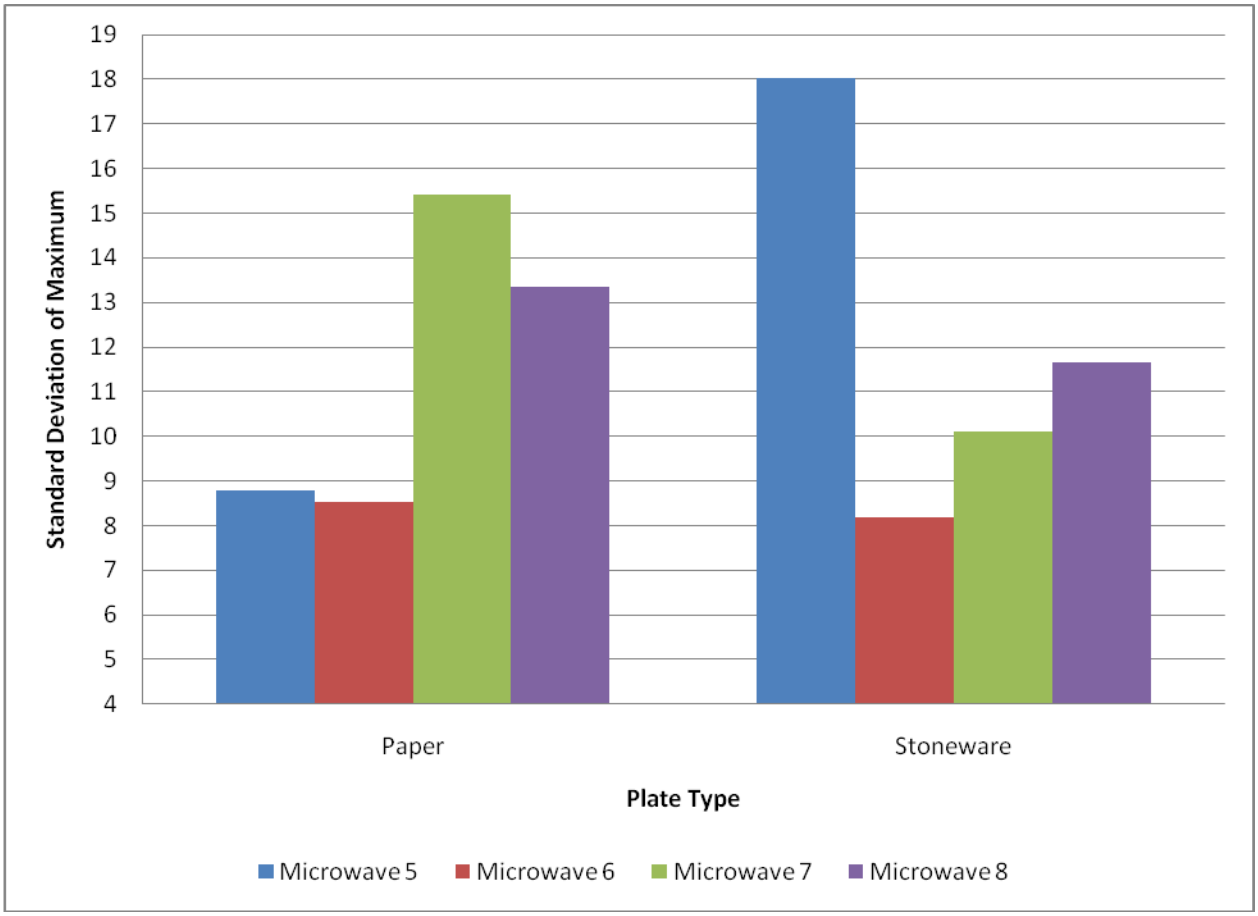

Figure 6-2 – Interaction effect between microwave and plate type on standard deviation among maximum temperatures for calzones in high-watt microwave study.

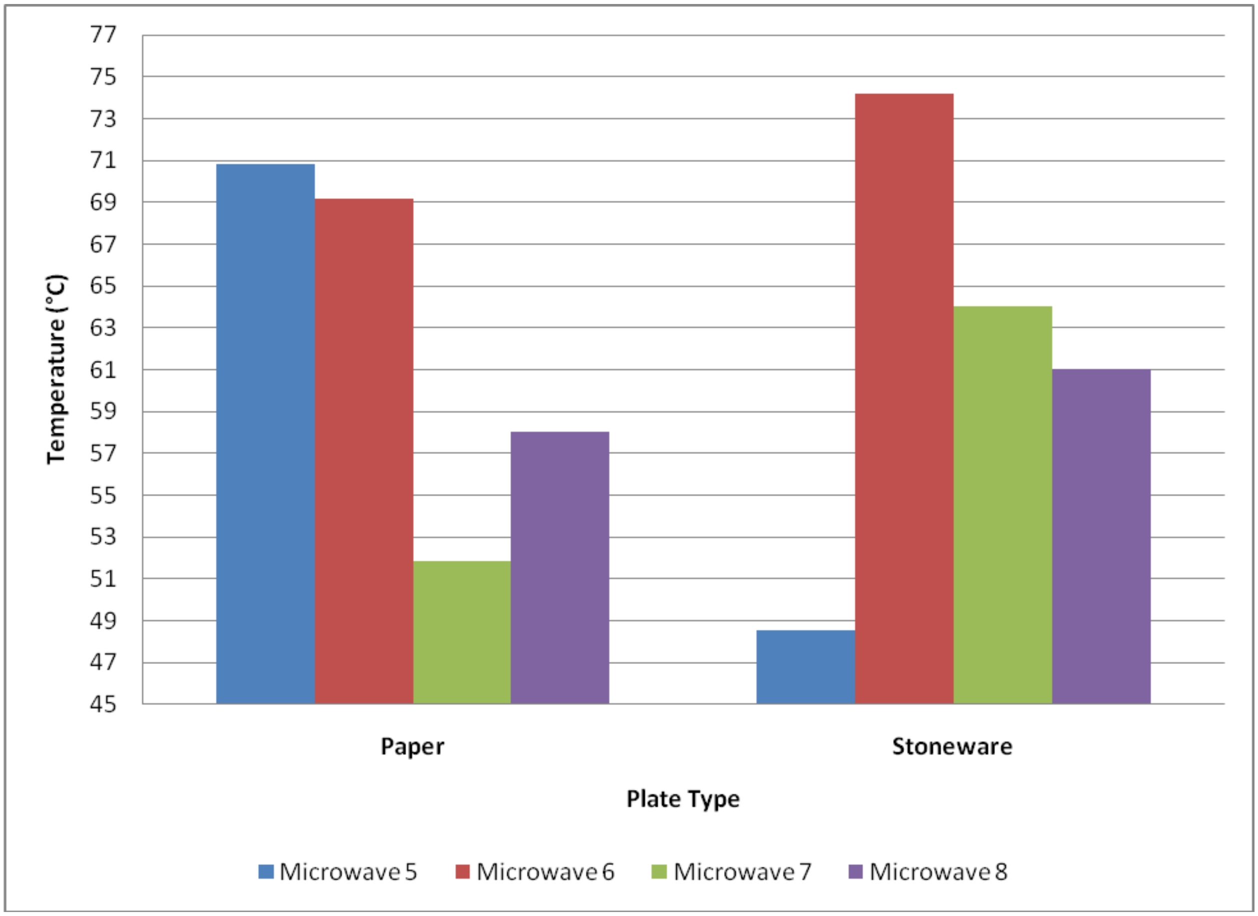

Figure 6-3 – Interaction effect between microwave and plate type on lowest maximum temperatures of calzones in high-watt microwaves study.

A significant interaction was detected between the microwave and plate type on grams of filling leaked ($p<.05$) (Figure 6-4). Calzones heated in microwaves 5 and 8 have lower filling leakage when heated on stoneware plates, and microwaves 6 and 7 have higher filling leakage on stoneware plates. Calzones heated in microwave 5 had significantly higher percent weight loss when heated on paper plates compared to stoneware plates (Figure 6-5). This effect was much larger than in all the other microwaves.

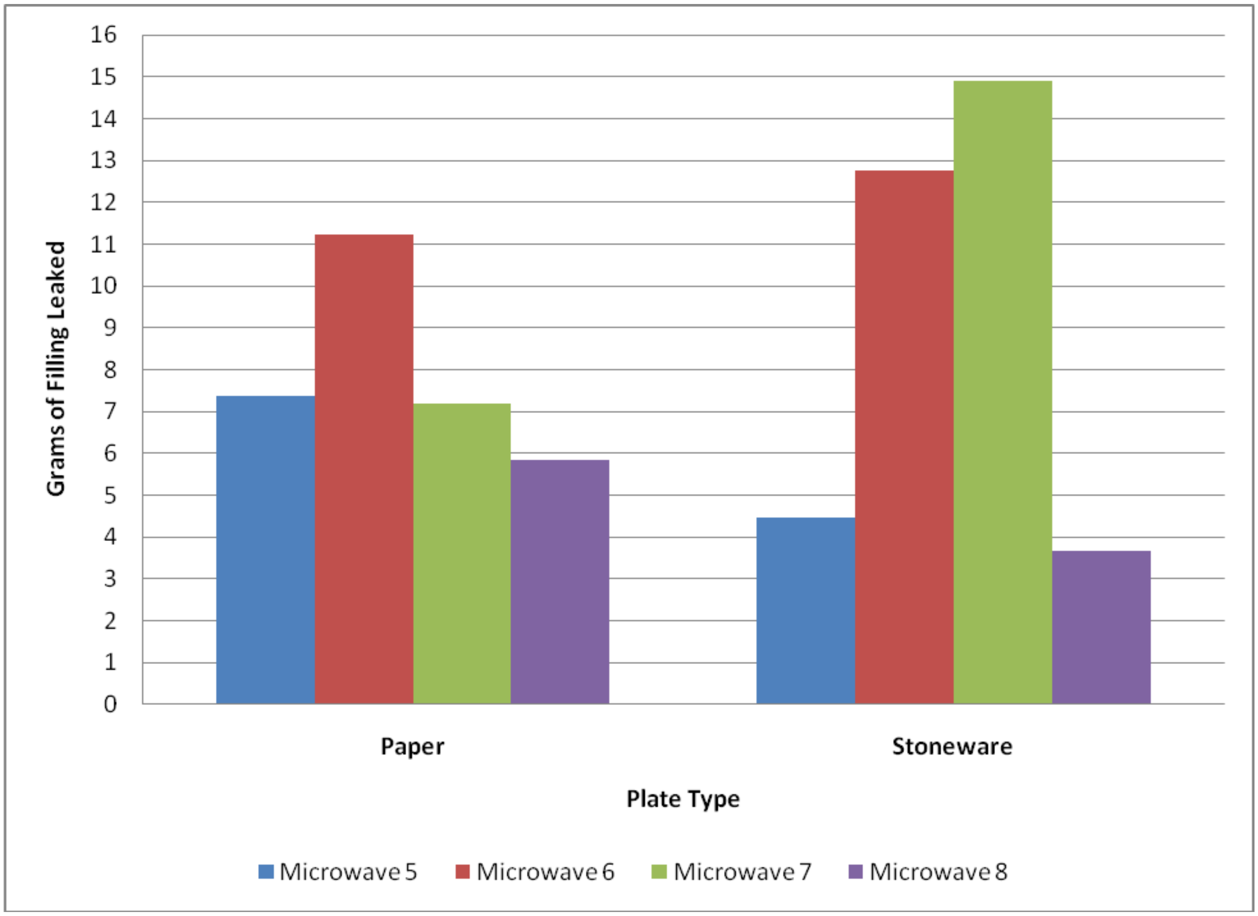

Figure 6-4 – Interaction effect between four high-wattage microwaves and two plate types on mean grams of filling leaked for calzones in high-watt microwave study.

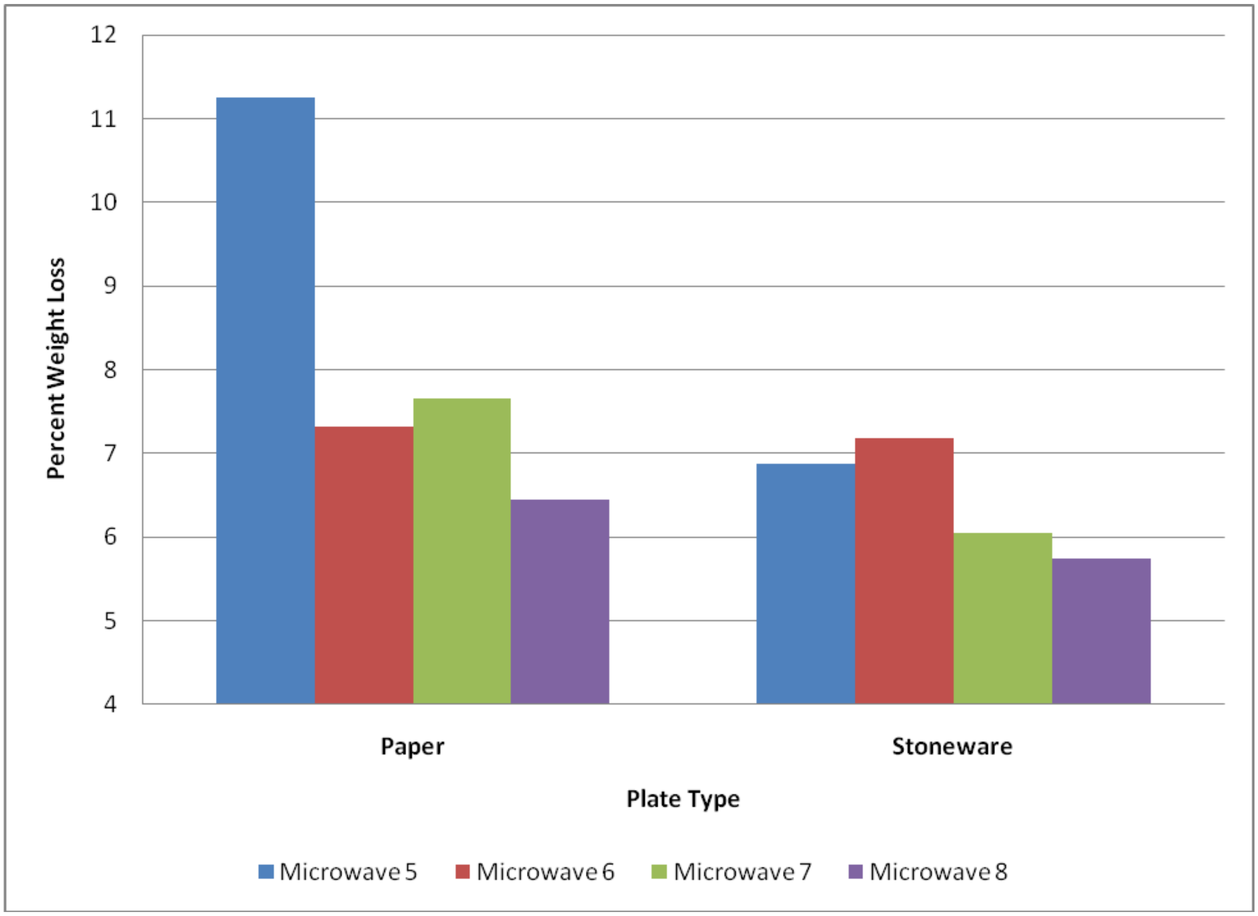

Figure 6-5 – Interaction effect between four high-wattage microwaves and two plate types on mean percent weight loss for calzones in high-watt microwave study.

The interaction effect illustrated that calzones heated similarly in microwaves 6 and 8 regardless of the plate type and this resulted in only small changes to the temperature responses or the grams of leaked filling. Both microwaves had slightly hotter temperatures when heated on a stoneware plate versus the paper plate. In microwave 5, calzones heated much hotter when on paper plates compared to stoneware. Microwave 5 exhibited behavior that was more like the low-watt microwaves, although with respect to measured wattage and size, it was in the upper range for cavity size in this wattage category and in the middle of the measured wattage. In microwave 7, calzones heated much hotter when on stoneware plates. This interaction further stresses the need to test multiple microwaves and plate types in cooking instruction validation testing.

Grams of Filling Leaked and Percent Weight Loss Compared to Temperatures

Neither of these two measures would be a reliable predictor of any of the maximum temperature responses. The correlation coefficients were all below 0.6 which would not be strong enough to rely on for food safety. There seems to be high variability in grams of filling lost which may be a result of seam integrity as well as increasing temperature of the filling. For the weight loss, the grams of filling leaked were so high in the trial runs that the grams of filling were added back to the calzone weight after heating in order for any reasonable weight loss to be calculated. Thus the percent weight loss was confounded with the grams of leaked filling which does not seem to be wholly related to temperature.

Probe Position and Depth

The 14 probes were categorized according to position and depth. There were six probes on the exterior and eight probes on the interior. The average maximum temperature across the entire study for the exterior probes was 89.1 +/-10°C and the average maximum for the interior probes was 78.2 +/-11°C. The probes were also divided by those above 8mm depth and those below 8mm depth. The average temperature of probes above 8mm depth was 82.6 +/-12°C and the average temperature of probes below 8mm depth was 83.2+/- 14°C. Greater variability exists from the exterior to the interior than from the top to the bottom but not significant in either case.

Probe position from exterior to interior and from top to bottom was examined but not found to vary greatly from top to bottom; however, the calzone was typically colder on the interior than the exterior. This was not universally true. In the 17 runs that passed killstep, the lowest maximum temperature was recorded in an exterior probe 29% of the time. Lowest maximum temperatures in probes only millimeters apart could easily vary 15°C or more indicating the usefulness of as many probes as was practical. Testing only the interior of the sample is not recommended since the exterior could sometimes record the coldest temperature.

Pass Killstep

For this food system, the pH of the filling was 6.33 and the a_w of the filling was 0.978. The Z-value (13) and the D-value (2.33 s), with a reference temperature of 160°F (71.1°C), were provided by the company from studies they conducted on this food system. Considering manufacturing practices, the killstep goal for this product during the consumer preparation is a 5-log reduction and occurs at 71.1°C instantaneous, or a time/temperature combination that is equivalent to provide a 5-log reduction. If the lowest maximum temperature achieved was 71.1°C, then the run passed killstep. If the lowest maximum was not at or above 71.1°C, the temperature data was analyzed with the AMI Foundation Lethality Spreadsheet to determine if killstep was achieved (Table 6-9). There were 12 runs which had a lowest maximum temperature above 71.1°C. There were 12 runs for which the lowest maximum was at least 63°C, but did not achieve 71.1°C and these runs were analyzed. Of these runs, only five of those runs passed the analysis. Table 6-9 shows the lethality for the five runs that didn't hit 71.1°C but passed killstep as calculated with the AMI Foundation spreadsheet. The cells shaded in yellow indicate when a 5-log reduction was achieved. The maximum temperature is bolded. The AMI Foundation Lethality Spreadsheet is attached in Appendix B. The highest percentage of runs that passed were heated in microwave 6, heated for the maximum time of 100 seconds and heated on paper plates (Table 6-8).

Table 6-8 – Percentage of runs that passed killstep sorted by microwave, time and plate type.

Run that passed killstep					
Microwave	**% Passed**	**Time**	**% Passed**	**Plate type**	**% Passed**
5	**24**	80 s	**29**	stoneware	**41**
6	**47**	90 s	**17**	paper	**59**
7	**12**	100 s	**53**		
8	**17**				

Of the 17 runs that passed by virtue of reaching 71.1°C or an equivalent time/temperature when analyzed using the spreadsheet, seven of them had only one repetition pass. The other ten runs comprise a set of five runs where both repetitions passed. In the set of five runs where both repetitions passed, four of the five sets were heated on paper plates and three sets were heated for 100 seconds, one for 90 seconds and one for 80 seconds. Of the ten runs where both repetitions did not pass, the average temperature of the lowest maximum from the repetition that didn't pass was 11 °C lower than the average of the repetition that passed.

Runs that passed killstep were not always repeatable indicating that the times tested were not sufficient to achieve killstep to the degree needed for food safety. Additional time was warranted. The goal of this study was not to determine the cooking instructions that would provide for killstep as that would limit the ability to distinguish between factors. During heating of high moisture products, a plateau is reached at boiling point and a certain amount of time is spent before enough moisture can be driven off and temperatures can rise again. If all the temperatures had reached boiling point, and temperatures were only measured post-heating, it would be impossible to tell how long a product had spent at or near boiling. The times chosen for this study were intended to provide for discernment between factors.

Table 6-9 – Runs that didn't reach 71.1 °C but reached a lethality via cumulative time temperature. [a]

Lethality calculations for runs with lowest maximum below 71.1 °C												
TIME (sec.)	**RUN 39, Probe 12**	**Log reduction**	**RUN 18, Probe 4**	**Log Reduction**	**RUN 18, Probe 10**	**Log Reduction**	**RUN 32, Probe 7**	**Log Reduction**	**RUN 10, Probe 9**	**Log Reduction**	**RUN 23, Probe 7**	**Log Reduction**
0	61.5886	0	52.1395	0	47.9524	0	65.71	0	48.60167	0	63.52722	0
5	67.8664	0.432913	54.5324	0.007968	51.0397	0.002451	67.383	0.518672	51.36444	0.002799	66.12889	0.314786
10	68.3471	1.258831	56.4286	0.023348	53.4939	0.008138	67.6464	1.20112	53.52111	0.008715	67.57278	0.881248
15	**69.0961**	2.267815	58.0262	0.049847	55.451	0.019323	68.6626	2.048246	55.24222	0.019465	68.70389	1.726639
20	68.74	3.336122	59.3666	0.091777	57.149	0.03912	**69.0835**	3.102009	56.69611	0.03711	68.82444	2.74235
25	67.3301	4.161424	60.4979	0.153555	58.5299	0.07107	68.5764	4.142446	57.93389	0.064015	**69.0467**	3.815581
30	66.5832	4.736188	61.4989	0.240039	59.7215	0.118925	67.629	4.974279	59.05	0.103028	68.61111	4.854776
35	65.3749	5.16185	62.6529	0.362481	59.9465	0.177875	67.4943	5.666568	60.03222	0.157348	68.49278	5.80403
40	64.6853	5.472509	63.4307	0.52756	60.9422	0.250346	66.9231	6.287602	60.89	0.229972	68.19056	6.692605
45	64.6668	5.748341	64.1317	0.736223	61.6809	0.345361	67.1488	6.873308	61.66278	0.323989	67.61722	7.467755
50	64.9496	6.036334	64.8433	0.997634	62.482	0.466958	67.0089	7.466843	62.31667	0.441762	66.34889	8.055097
55	64.4141	6.313683	65.3804	1.315742	63.1544	0.620381	66.5328	8.006281	62.915	0.585428	66.27056	8.519481
60	63.3254	6.530209	65.8238	1.687234	65.4995	0.884604	65.3677	8.42751	63.435	0.756941	66.06778	8.963712
65	61.5312	6.670471	66.3024	2.11772	67.7284	1.428885	63.3269	8.689154	63.895	0.957304	65.35444	9.349867
70	60.4619	6.757058	66.4664	2.593419	66.4611	2.0375	61.9785	8.837216	64.32889	1.188284	64.87944	9.668238
75	60.1644	6.825771	66.7206	3.102155	67.7558	2.649317	60.8851	8.936757	64.70889	1.451116	64.02111	9.927318
80	58.4959	6.877726	66.9844	3.654717	67.4943	3.356193	60.2349	9.011412	65.05222	1.745971	63.30667	10.12837
85	60.0104	6.928112	67.2191	4.252871	67.4803	4.032111	60.3352	9.079444	65.37167	2.073619	62.97111	10.29758
90	60.2534	6.992943	67.4434	4.896393	67.5365	4.712616	61.0769	9.157783	65.65056	2.433945	62.29722	10.44226
95	60.8509	7.067349	67.6076	5.580826	67.6219	5.408694	61.3575	9.249439	65.90944	2.82647	61.56278	10.55798
100	58.0667	7.124852	67.7626	6.30096	67.6671	6.119368	61.6385	9.349679	66.10889	3.248601	61.97667	10.66742
105	57.7679	7.156864	67.8875	7.053872	67.723	6.841598	62.0193	9.461165	66.30778	3.698405	62.03333	10.78513
110	58.2252	7.189745	67.9636	7.831202	67.7487	7.573261	61.1754	9.565464	66.47056	4.174825	61.71333	10.89815
115	59.2625	7.231931	68.0639	8.630745	67.7851	8.312209	60.5654	9.647832	66.62944	4.676304	61.17444	10.99694
120	59.9841	7.287381	**68.1216**	9.450611	**67.8062**	9.057954	59.9892	9.715974	**66.7883**	5.20384	60.91944	11.08374

[a] Temperatures in bold are the maximum temperatures, the cells shaded in yellow indicate when a 5 log reduction was achieved.

Conclusions

A previous study with lower wattage microwaves indicated that microwaves, plate type, and heat time had significant effects on the heating of calzones in microwaves. This study found that in high wattage microwaves, microwaves and heat time also significant factors and that the effect of plate type was dependent on the exact microwave used. In many cases significant differences were observed in standard deviation of maximum temperatures. In all cases, the higher the temperatures recorded, the lower the standard deviations. This does not seem to be a result of better uniformity from one level of a factor than another, but rather a side effect of temperatures approaching the boiling point where a temporary ceiling is reached on temperature. Grams of filling leaked and percent weight loss did not seem to be strong indicators of internal temperature. This is thought to be an artifact of poor seam integrity of the calzone, allowing for leakage and weight loss even when high temperatures were not achieved. Analysis of the probes from top to bottom and exterior to interior indicate that a sufficient number of probes should be utilized across the entire area of the calzone to ensure that potential cold spots are detected. In using the results of this experiment to design validation testing for calzones, it is recommended that testing be done at multiple wattage ranges and multiple microwaves within each wattage range. The interaction between plate type and microwave indicate that testing should include some paper plates as well as stoneware plates, since plate type effect was not consistent across all microwaves. If the cooking instructions are to include a recommendation to "heat further if not hot enough", the time interval suggested should be greater than 10 seconds.

Thesis Conclusions

For low-watt microwaves (700-800 watts), all of the factors studied had significant effects on heating of calzones with the exception of flip step. For high-watt microwaves (1000-1200 watts), microwaves and heat time were significant factors; however, plate type was not a significant factor. Flip step was employed in all runs in the higher-wattage microwaves since it was determined to be critical for achieving acceptable temperatures in some microwaves.

Plate type appears critical to heating the calzone in many microwaves and various plate types should be tested when developing instructions for NRTE products. It was thought that the high-watt microwaves are designed for larger loads and thus were not affected by the presence of the stoneware plates to the extent that some of the lower-wattage microwaves were.

Neither the grams of filling lost nor the percent weight loss appear to be reliable predictors of temperature. The correlation coefficients were all below 0.6 which would not be strong enough to rely on for food safety. Testing only the interior of the sample is not recommended since the exterior could sometimes record the coldest temperature. Runs that passed killstep were not always repeatable indicating that the times tested were not sufficient to achieve killstep to the degree necessary for food safety. Additional time was warranted. Instructing consumers to let the product stand for 1 minute after heating would not be sufficient for food safety in all cases. If a 1 minute stand time is desired, additional time would be required in the heating step.

Implications for Developers

In using the results of this experiment to design validation testing for calzones, it is recommended that testing be done at multiple wattage ranges and multiple microwaves within each wattage range. Multiple microwaves in each wattage range should be included because wattage alone cannot predict performance.

The presence of interactions between microwaves and plate type further stresses the need to test multiple microwaves and plate types in cooking instruction validation testing. The interaction between plate type and microwave indicate that testing should include some paper plates as well as stoneware plates, since plate type effect was not consistent across all microwaves. Stoneware plates should be preferentially chosen as the test plate for safety reasons since products tended to be significantly colder when heated on stoneware plates, especially in lower wattage microwaves.

If the cooking instructions are to include a recommendation to “heat further if not hot enough”, the time interval suggested should be greater than 10 seconds since this time interval did not always produce a significant increase in temperature.

Temperature collection should be executed with an apparatus that can measure as many internal temperatures as is feasible, choosing locations in the exterior and interior and from top to bottom.

The observation of interactions between microwave and flip step indicate the need for utilizing the flip step in the cooking instructions. An understanding of what happens when the flip step is not employed should also be understood.

Any quality issues such as filling leakage should be optimized so as not to confuse the consumer who may assume cooking is complete when they see filling begin to leak. In this study, leakage did not correlate strongly to temperature. Visual indicators are often the only way consumers understand if the cooking is complete in a microwave, so any visual indicators of doneness should not occur prior to killstep being achieved.

These consumer-influenced factors must also be understood within the context of process variability, so further study is necessary to ensure all factors which may affect heating are understood.

A stand-time of one minute as a last step in the directions may not be sufficient to prove a killstep after heating; however, increasing the stand time must be balanced against the likelihood that consumers will wait longer than one minute.

Implications for Consumers

Read and follow package directions exactly. Use a temperature probe to ensure that your product is fully heated and measure the temperature in more than one location because there can be wide variability in temperatures throughout. Always adhere to recommended stand times to allow for equilibration of temperatures and full cooking.

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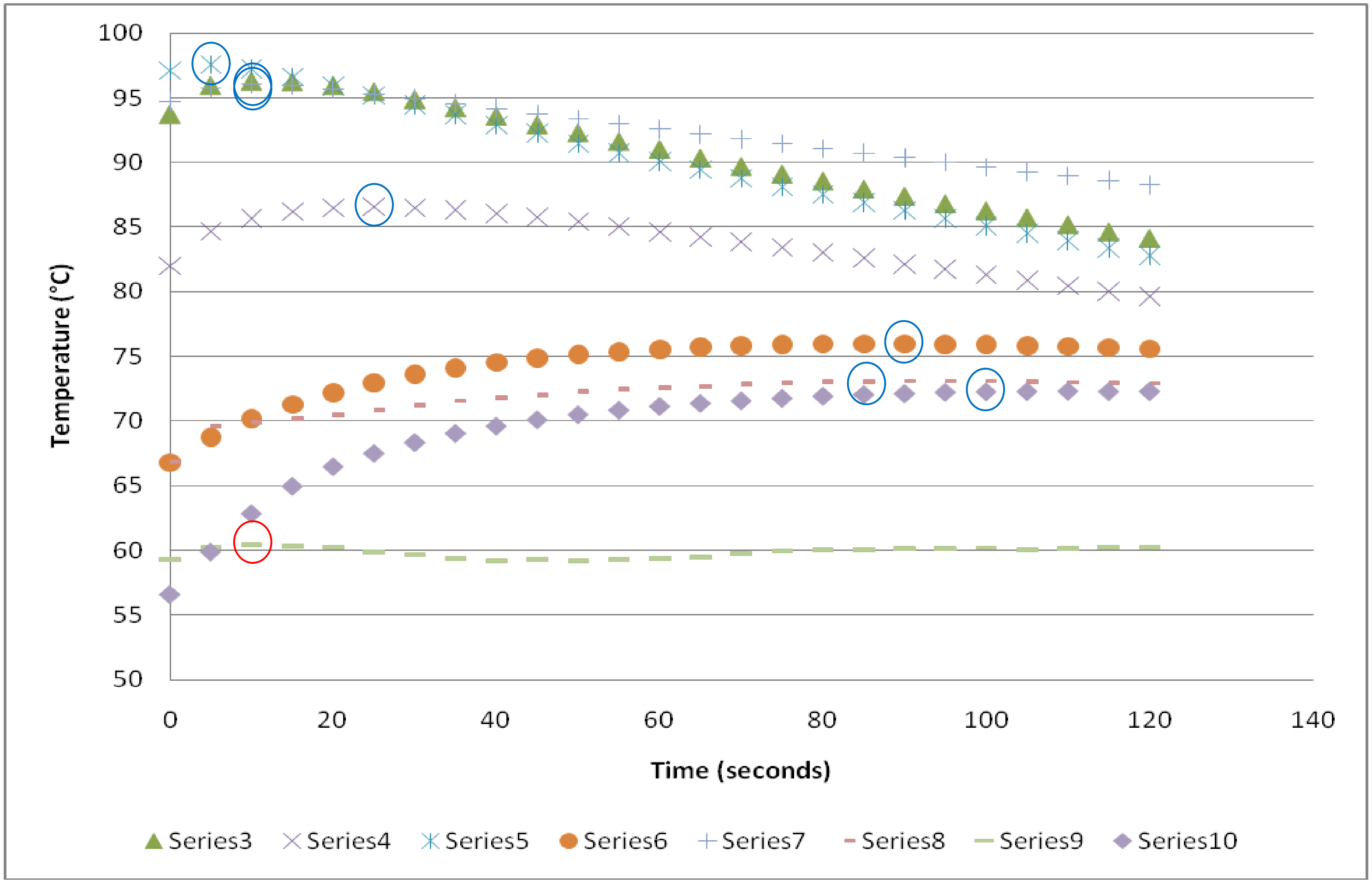
Appendix A - Example of temperature data from selected probes of typical microwave run



The series represent individual probes. The maximums for each run are circled, lowest maximum for the run is circled in red.

Appendix B - AMI Foundation Lethality Spreadsheet

User Must:

1. Identify organism and product of concern

2. Provide at least 20 time/temp data points

Instructions:

1. Select the organism and product of concern and identify corresponding T ref, z, and D values in the table. These values should be obtained from your own companies challenge study data, from scientific literature, or other reliable sources. These values need to be relevant and appropriate for the type of product and the organism of concern.

2. Enter the T ref, z, and D values into the appropriate labeled cells below the table that contains the lethality data from literature.

3. Clear and enter at least 20 time/temp data points into the data table.

4. Once the table is completed, a cumulative F value will be given as the very last number in the right hand column of the data table. This number adds up the lethality values for each time interval and calculates an approximation of the area under the lethal rate curve.

5. After the data is entered, a core temperature and a lethality curve are produced.

6. The total log reduction of the process is automatically determined by dividing the cumulative F value by the D value that was entered into the appropriate labeled cell. The resulting value equals the total log reduction of the process.

7. By using these estimates, you or a process authority should determine if the process meets regulatory requirements as safe. Additional documents, such as Appendix A, which discuss desired log reductions should also be considered when evaluating a lethality process.

Note: This model is a tool for calculating F-values. To ensure correct results, the proper z, T-ref, and D-values for each product and organism must be used.

z = 13 ºF **T ref=** 160 ºF

D = 0.03883 min

Log Reduction of Process = 0.00

Data Table

Time (min)	Core Temp (ºF)	F-value (min)	Log Reduction
		0.000	0.000
		0.000	0.000
		0.000	0.000
		0.000	0.000
		0.000	0.000
		0.000	0.000
		0.000	0.000
		0.000	0.000
		0.000	0.000
		0.000	0.000
		0.000	0.000
		0.000	0.000
		0.000	0.000
		0.000	0.000
		0.000	0.000
		0.000	0.000
		0.000	0.000
		0.000	0.000
		0.000	0.000

Spreadsheet can be accessed at:

http://www.amif.org/ht/d/sp/i/26870/pid/26870