COOLING RATES OF SOLID AND LIQUID FOOD SAMPLES IN TWO RETHERMALIZATION EQUIPMENT DEVICES

By

SHERRY JO ANDERSON

Bachelor of Science

Central Missouri State University

Warrensburg, Missouri

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Thesis Approved:

Esther Winterfeldt
Thesis Adviser

Anna M. Gorman

Lee L Ebro

Norman N Durham
Dean of the Graduate College

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CHAPTER I

INTRODUCTION

Hospital foodservice systems are faced with strategic demands not known a decade ago. Many hospital foodservice administrators feel that modern foodservice systems offer the most promising means of combating the many problems they face--shortage of skilled labor, increasing labor cost, low productivity, and antiquated delivery systems that result in losses in food quality and temperature between preparation and service with predictably poor patient response to hospital food (1) (2).

The ultimate goal of any foodservice system is to provide patients a nourishing meal of high quality, served at optimum temperatures. The statement "keep hot foods hot and cold foods cold" is familiar to everyone employed in the foodservice industry. "Cold food" should always be maintained at 45°F or cooler while the optimum temperature for serving "hot food" should be at least 140°F. The 45°F to 140°F temperature range, often referred to as the "danger zone," is the most vulnerable area for the reproduction of organisms responsible for food spoilage.

In an effort to provide hot food to patients, many researchers have discussed the decision alternatives concerning centralized versus decentralized rethermalization in modern hospital cook-chill and cook-freeze foodservice systems. Koogler and Nicholance (3) have described the logistical advantages of decentralized rethermalization which are as dependent on management practices as they are on the physical location. Decentralized rethermalization can result in better food temperatures as the point of final heating is close to the patient, but will result in better temperatures only as long as such management practices are properly implemented and controlled. Close coordination must also be maintained between the galley workers and those employees responsible for patient tray delivery.

Providing patients quality food served at optimum temperatures involves a coordinated effort between the nursing and dietary departments to assure patient satisfaction of meals. Because of the diversification or departmental responsibilities and the immediacy of patient care, delays in patient-ready trays are commonly incurred. In such cases, the temperature of patient-ready food would depend more on the delivery system and components, such as the type of serviceware utilized, than on the rethermalization location (3).

Despite the abundance of literature on foodservice systems, little data are available on the cooling rate or cooling time of food and the corresponding rethermalization equipment commonly employed by healthcare facilities utilizing decentralized rethermalization. Thus, it seems it would be of importance to examine the maximum amount of time solid and liquid food samples can be held above 140°F through a comparison of two rethermalization devices used by hospital foodservice systems with decentralized rethermalization.

Purpose and Objectives

The purpose of this study was to compare the cooling rate (time) of solid and liquid food samples rethermalized decentrally in a ducted-type forced air convection oven and a microwave oven to determine the maximum amount of time food can be held above 140°F. The objectives of this research were:

1. To determine which of the two rethermalization equipment devices--microwave oven or ducted-type forced air convection oven--provides better heat retention of four ounce portions of mashed potatoes and four ounce portions of beef broth.
2. To determine the types of serviceware (entree plate and soup bowl) and packaging (serviceware covering) materials applicable for use in both the microwave oven and convection oven which provide maximum heat retention of food.
3. To make recommendations regarding selection of rethermalization equipment in decentralized hospital foodservice systems based on the findings of the study.

Hypotheses

The following hypotheses were tested by the study:

1. There will be no significant difference in the cooling rate of mashed potato or of beef broth samples rethermalized via microwave oven versus ducted-type forced air convection oven.
2. There is no significant difference in the cooling rate of mashed potatoes or of beef broth rethermalized by microwave oven versus ducted-type forced air convection oven using round or rectangular shaped pans (mashed potatoes), two types of soup bowls (beef broth), or two brands of serviceware covering materials.

Assumptions

The following assumptions applied to the study:

1. Both ovens performed according to the manufacturer's specifications.
2. The pyrometer (thermometer) performed within specification tolerances.
3. Since the experiment was performed in a commercial laboratory where temperature and humidity were controlled according to the requirements of the industry, it was assumed that there was no variation in these controls.

Limitations

The following limitations were recognized in the study:

1. Other packaging materials were not investigated.
2. Only two foods were tested.
3. Only two rethermalization equipment devices were tested.

Definition of Terms

The following definitions were accepted for the study:

1. Ducted-type forced air convection oven. In this oven forced circulation of hot air is kept in motion in the oven cavity and heats the food by convection (4).
2. Microwave oven. The microwave oven heats by radiation using a single length of electromagnetic waves that concentrates all the energy at a single frequency. A magnetron converts electrical power into microwaves within the boxlike cavity

which encloses the food within sealed metallic walls. The distributed energy absorbed by the food is received directly from the microwave source or reflected from the walls (5) (6).

3. Healthcare industry. The healthcare industry includes hospitals and extended care facilities (nursing homes) which provide general, intermediate, and/or skilled medical and total care for such institutionalized people.
4. Foodservice systems. A facility where quantities of food are routinely provided for individual consumption and service. Food may be totally prepared, totally purchased, or a combination of purchased/prepared. This facility includes any place regardless of whether consumption is on or off the premises (7).
5. Rethermalization. Rethermalization is the final application of heat to a partially cooked and chilled or frozen menu item to achieve the desired internal temperature for service. The terms end-heating, reconstitution, end-cooking, re-heating, and heat processing have also been used to connote the process of rethermalization which can occur centrally or decentrally (7) (8).
6. Galley. A galley is a food serving area located on the patient care unit which is equipped to rethermalize food for patient trays. Pantry is also used to mean galley (8).
7. Ready-prepared foodservice system. Prepared menu items are always stored and ready for final assembly and rethermalization. Menu items, such as entrees, undergo two stages of heat processing. The first heating occurs in quantity production, the second heating occurs after storage and is a pre-service rethermalization at the galley. The two main variations of the

ready-prepared foodservice concept are the cook-chill (chilled) and cook-freeze (frozen) foodservice systems (7).

8. Decentralized rethermalization. The second and final heating of ready-prepared menu items which occurs in a galley.

CHAPTER II

REVIEW OF LITERATURE

The review of literature indicates that the development of modern hospital foodservice systems started during the time of Florence Nightengale. A major problem in foodservice systems is a means of controlling food temperature. Preferred food temperatures are discussed as well as the cooling rates of food in different containers and as related to various preparation and service methods. The literature review also outlines those factors which must be considered for the proper use of the microwave oven and the ducted-type forced air convection oven.

Development of Foodservice Systems

Feeding hospitalized patients has been studied since the time of Florence Nightengale. At that time, food preparation and feeding of patients were the responsibility of the nurse. With the passage of nearly a century, the complexities of medical diagnosis and treatment led to the development of a number of medical auxillary technicians and professions whose responsibilities would formerly have been considered to be some part of nursing. The demands made by requirements for special diets for particular diseases and conditions, and the attention and time required for such preparation, led to the introduction of the dietitian into the larger teaching hospitals, during the period between World War I and World War II.

After World War II, foodservice managers were appointed to oversee and assist in the preparation of food for hospitalized patients. The tripartite organization of nurses, dietitians, and kitchen managers was developed, all of whom shared the responsibility for serving the right food at the right time and place. This historical development accounts for conditions found in hospitals today (9) (10).

The technology of mass feeding in the healthcare industry was accelerated by scientific research as well as by social and political developments. In 1978, the growing healthcare industry was the third largest in expenditures in the United States, with foodservice operations accounting for approximately eight percent of total hospital expenditures. Hospital foodservice administrators were forced to make a thorough analysis of their operations as a result of the emphasis on cost containment and government constraints plus increased demand for improved service (11) (12) (13).

Every mass feeding operation experienced the effects of spiraling food and labor costs as well as the growing shortage of skilled and unskilled people in the work force. Many hospital foodservice administrators felt that modern foodservice systems offer the most promising means to combat those problems and to upgrade the efficiency, effectiveness, and productivity in dietary departments. But, at the same time, the technological advancements in food preparation, processing, equipment, and packaging created new concepts that require investigation and evaluation (1) (2) (13).

Numerous studies evaluated the cost effectiveness, labor saving potential, rethermalization equipment effectiveness, microbiological characteristics, and productivity improvements incurred by modern foodservice systems. To date, no research has been conducted on the cooling rate of food and materials which hold and cover food and the various rethermalization equipment devices utilized in modern foodservice systems which contribute to the ultimate goal of patient satisfaction.

Food Temperatures

Whatever food preparation or distribution system is utilized in hospital feeding programs, the foodservice administrators' ultimate goal is to serve patients "hot food hot and cold food cold." The dilemma of keeping hot food hot is a greater problem in hospital foodservice than in other facets of the foodservice industry because patient-ready trays are frequently delayed before the patient is served the meal. As a result, food should begin at a high temperature to compensate for this predictable difference in time. However, the temperature should not be too high to result in color and nutrient losses. Consideration of serviceware used to hold the food should include materials which can maintain optimal food temperatures (3).

Hospital patients demand high quality food served attractively at optimum temperatures for the various food items. The quality of food held before service, with respect to temperature, is governed by such variables as the time lapse between service and consumption, preferred temperature of food items, material used to hold and cover the food, and the cooling rate of food (14) (15) (16).

Temperature ranges for four classifications of food were determined by Blaker et al. (15). Their findings indicated temperature preferences as follows: soup, 145°F to 150°F; beverages, 145°F to 150°F; potatoes and vegetables, 140°F to 145°F; and entrees, 140°F to 145°F. The lapsed time between portioning and eating the food was recorded for a table-service dining room and the straight-line and hollow-line cafeteria layouts. The time depended on the physical arrangement, speed of service, and type of operation. The desirable food holding temperatures were then determined by the holding time and the corresponding cooling rates of the various food items. For example, with a time lapse of three minutes and ten seconds recorded for the hollow-square cafeteria, the recommended food holding temperatures were: soup and mashed potatoes, 156°F; ham and broccoli, 159°F; and 160°F for tea.

Thomas (17) reported desirable temperatures for serving food to hospital patients and indicated that individuals preferred to eat carrots, peas, mashed potatoes, cream soup, and broth soup within the 140°F to 150°F temperature range. Foley and Gilham (18) conducted a study of acceptable temperatures of various food items served in hospitals. According to the study, food served to patients should be at least 160°F, but preferably 170°F. Food temperature preferences of surgical patients were studied by Thompson and Johnson (19) at Grace-New Haven Community Hospital. The recommended temperature standards for potatoes and other vegetables ranged from 160°F to 170°F and from 150°F to 160°F for meat.

Cooling Rates in Various Types of Containers

The temperature of food served to patients may be affected by the type of serviceware material used. Ross (14) determined the cooling rate of beverages in various individual servers. The findings indicated that the temperature of food as it reached the consumer was affected by the amount of time elapsing between service and consumption, the food-service system used, and the temperature of food at the time of service.

Thomas (17) conducted a study of the cooling rate of food served in disposable plastic and china containers with a decentralized delivery system. Food in the plastic containers was up to 6°F higher at the patients' bedside than the same food served in china containers.

In 1955, May (20) conducted a study of 15 hospitals (170 to 270 bed range) which utilized various assembly and distribution methods in an effort to determine which system provided "good food" in the most efficient and economical manner. Part II of the study dealt with the time-temperature relationships of various types of food portioned on institutional chinaware. The liquid category of food included coffee, consomme, and vegetable and cream of mushroom soup. Vegetables used in a second category included mashed potatoes, spinach, peas, squash, sliced carrots and beets, asparagus, and green beans. The homogeneous liquid and solid food items, such as consomme and mashed potatoes, were easier in obtaining an accurate temperature recording than foods such as peas, carrots, beets, asparagus, and green beans.

The initial food temperature made a difference in the ultimate cooling rate of foods. The cooling rate or heat loss in foods with initial temperatures above 150°F was less than those initial temperatures which were below 150°F. Under these conditions, the cooling rates of the various food items are shown in Table I (Appendix A).

Cooling Rates as Related to Preparation and Service Methods

The type of preparation system and the type of distribution or service method may affect temperature losses in food. Gee and Axelrod (21) determined the heat loss of food samples through a comparison of the pellet system of foodservice with a system of hot and cold food carts. As initial heat loss was apparent in both systems, there was no appreciable advantage in one system over the other although the pellet system was found to permit more rapid overall service. The cooling rates of potatoes and soup, averaged from 600 temperature recordings, are shown in Table II (Appendix A). The average food temperature in the hot and cold cart was 142°F although 18 minutes elapsed before the first tray was served. The average time required to serve the first tray on the pellet system was 12 minutes after it left the kitchen at an average of 153°F.

A research project in Food Facilities planning was conducted by advanced students in the School of Hotel Administration at Cornell University (22). The purpose was to make a comparative study between hospitals utilizing convenience foods versus conventional preparation. These researchers concluded that improper temperature of food served to patients was due to many factors, but the "overriding factor is time." Results of this study revealed that "minimizing the food's exposed surface area, maximizing the mass or density of foodstuff, container design and temperature, all influence heat loss" (22, p. 103).

Factors in the Use of Microwave Ovens

Proper use of the microwave oven in foodservice systems requires knowledge of many factors which contribute to a satisfactory food product. Knowledge of the method of heat transfer and the principles of microwave energy distribution, plus food plating procedures, types of containers and covering materials utilized, and consideration of standing time must be delineated as important factors in the proper use of a microwave oven.

Heat Transfer and Distribution

Heat transfer is the transmission of thermal energy from one point to another when temperature differences exist. In conventional cooking heat is transferred by conduction, convection, and radiation.

Microwave ovens heat food by the radiant process through absorption of single-length electromagnetic energy waves that fall between light and radio waves in frequency. Microwaves do not contain heat but are capable of generating heat as they pass through food and create molecular friction. A magnetron generates the electromagnetic energy while the wave guide delivers this energy into the oven cavity. Food and other polar substances increase in temperature by absorbing the microwave energy. This energy is converted into heat within the food by molecular friction. Thus, rate of heating depends on the particular molecular and cellular structure of the particular food item (6) (23) (24) (25).

A wave stirrer distributes the waves as the microwave energy enters the oven cavity. The metal interior of the oven cavity reflects waves, and contributes to the microwave energy distribution pattern. Since microwave energy travels in straight lines, reflected waves contribute to a specific energy distribution, called the standing wave pattern (23).

According to Ringle and David (23, p. 46), "in the zone where the energy is reflected from the walls and floor of the oven cavity, the metal has a reducing effect close to its surface." Areas of high and low electric fields are thus produced. The result of this uneven energy distribution on food quality is a major problem of the microwave oven in a foodservice system (23) (24).

Numerous studies were undertaken to determine the electric field distribution in an effort to resolve the problem of uneven heating of food in the microwave oven (23) (25) (26) (27) (28). The electric field distribution of microwave energy varied among oven manufacturers. Ringle (23) recorded different patterns of energy distribution for each of three ovens of different manufacturers and/or model. On the other hand, Berntsen and David (28) reported that three ovens of the same manufacturer and model had identical patterns.

Van Zante (5) outlined additional factors which are responsible for the uneven heating of food in a microwave oven. According to Van Zante:

> Within a single, solid food, cooking can be uneven depending on shape, material components, inefficient stirring action of the stirrer, oven shape, and other factors. The food will need to be shielded, turned around, turned over, and perhaps relocated in the oven to overcome unevenness (p. 87).

Manufacturer-prepared operating manuals offer suggestions to achieve even heating of portioned food in the microwave oven. Preparation and portioning guidelines, time-tables for heating food in the microwave oven, special handling, and other particulars are a result of research findings concerning the electric field distribution in the microwave oven cavity.

Food Plating, Containers, and Coverings

Successful microwave reconstitution of food is very dependent on the proper portioning or plating of foodstuffs. Proper plating of food requires consideration of the following determinants as discussed by Van Zante (5):

> The food itself, the portion sizes (mass), the shaping of the portion, the rate of heat absorption (specific heat), the color (heat reflectance), the thickness of the portion, the size of the particles, the moisture content and juices, the amount and location of fat, the plate material and shape and the covering (p. 126).

Two techniques have been recommended for proper plating of mashed potatoes to be heated in a microwave oven. One authority recommended placing mashed potatoes at the plate rim by squeezing through a press, such as a cookie press (5). Copson et al. (24) suggested to depress the center of a scoop of mashed potatoes so that the greatest mass of food is concentrated towards the periphery.

The microwave oven created new problems in the choice of utensils. Because of the basic difference in the source of heat energy, many containers and coverings used in conventional cookery cannot be used in microwave cookery. The container for heating food in the microwave oven must be one that transmits the microwaves but does not reflect, absorb, or refract them (5).

According to Van Zante (5, p. 68), "the ideal container has yet to be made." In terms of optimum microwave performance, the ideal package would be circular in shape with a center void. The physical appearance of an ideal container for use in a microwave oven was described as one "that is round, has sides that angle toward the bottoms, has a concave bottom, and has no sharp turns" (5, p. 68). The chemical make-up of an ideal container should have low absorption of microwave power, be sufficiently tough in handling, have tolerance for both high and low temperatures, be easily fabricated, and have United States Department of Agriculture approval (5).

Container materials applicable for use in a microwave oven are glass, glass-ceramics, china, earthenware, plastic, wood, straw, and, in a few cases, metal. It was suggested that glass and glass-ceramics provide the most useful and versatile utensils for microwave applications (5). Payne and Dann (29) concurred with those recommendations.

Glass and glass-ceramics were recommended as they allow microwave energy to be transmitted to the food with a minimum of energy loss to the dish (29). Absorption of microwave energy by a container is referred to as "lossiness" or "loss," and is expressed as being low, medium, or high in "lossiness." If a container is hot to the touch after being placed into the microwave oven it is high in lossiness and least satisfactory for use (5).

China and earthenware are widely used for service in food establishments. These materials vary in degree of lossiness and are usually higher than glass in lossiness (5).

A laboratory study compared various brand-name containers for use in microwave ovens. The findings indicated a shallow square china container, as manufactured by Hall China Company, to possess medium lossiness (5).

A study which compared china plates and disposable plastic plates was undertaken by advanced students at the University of Wisconsin, Stout. It was concluded that china plates could be used in serving meals rethermalized in a microwave oven to patients in a hospital. Temperature increases in some foods after heating were possibly due to the particular containers utilized (5).

According to Payne and Dann (29, p. 5), "when food has absorbed energy and produced heat, the heat will be conducted from the food to the cooler dish at the point of contact." It is, therefore, possible to heat food to an acceptable serving temperature and find the food too cool to eat because this conduction has taken place.

This conduction can also occur because of the size, mass, and thickness of containers. According to Van Zante (5):

> Because of their thickness, earthenware containers are of high proportional mass (weight) relative to the amount of food contained. This high mass takes up heat by conduction from the heating food and thus causes quick cooling of the food after microwave heating (p. 69).

Other studies investigated microwave absorption with various container shapes. Laboratory studies have proven that round pans are superior to square pans because there are no corners where microwaves can become overconcentrated (5). Other researchers revealed that the size and shape of dishes most suitable for efficient energy use and cooking performance will vary according to the particular brand of microwave oven (29).

Dishes of food are generally covered prior to heating in a microwave oven. According to Copson (24), a cover serves four purposes as follows:

1. It is intended to surround the meal components with a moist atmosphere, to keep them from drying excessively. (For a crispy surface, it is not used.)
2. It keeps the meal hot for a reasonable period (15-20 min.).

3. It gives a slight pressure inside the cover to assist in the heating.
4. It contains the splatter, and volatiles (p. 329).

Plastic film, thermal-plastic wraps, plastics (produced from a wide variety of chemical polymers), wax paper, and paper and pulp-board derivatives may be used to cover food prior to rethermalization in a microwave oven. Glass, glass-ceramics, banquet-covers, and sometimes metal are also used to cover food for microwave heating (5) (24) (29) (30).

Standing Time

Standby equalizing time is an important factor to consider in the use of microwaves for cooking (24). According to Van Zante (5, p. 83), "'standing time' is the time during which food rises in temperature and further cooks after being withdrawn from the oven."

According to Copson (24, p. 324), with large masses of food, such as large roasts, cooking involves a "combination of direct heating by microwaves and conduction." Copson (24, p. 344) further states, "the purpose of standby time is to allow this heat to distribute itself through the roast so as to produce normal patterns of doneness."

Depending on individual preference of doneness, a roast should be removed from the microwave oven at a low temperature to allow for this conduction of heat from the periphery to the center of a product. Copson (24) suggested a 20 to 40 minute equalizing period for massive roasts.

Van Zante (5) noted that the continued cooking exhibited by standing time should be carefully controlled to prevent overcooking and product dehydration. Standing time should also be considered for vegetables and with small food masses or single portions.

A laboratory study was conducted to discover the effectiveness of various types of wraps on baking potatoes in order to prevent overcooking during standing time. Two kinds of potatoes and four wrapping treatments were used along with the unwrapped controls. Results indicated the potatoes wrapped in clear plastic film reached the highest internal temperature during cooking and held the heat the longest during standing time (5). Copson (24) suggested a standby time of about five minutes for cooking whole potatoes from a raw condition.

Factors in the Use of Ducted-Type Forced Air Convection Ovens

Use of a ducted-type forced air convection oven requires consideration of various factors in order to obtain a quality food product. A basic knowledge of convection heat transfer and distribution as well as the thermal processing conditions that cause heat transfer are outlined. The difference between a forced convection oven and a ducted-type forced air convection oven are discussed. Food plating procedures and the types of containers and container covering materials applicable for use in the ducted-type convection oven are described as well as standby time.

Heat Transfer and Distribution

Heat transfer is the transmission of thermal energy from one point to another when temperature differences exist. The rate at which thermal energy enters food in an oven depends on the following factors as described by Livingston and Chang (31):

> . . . the type of heating favored by the oven: i.e., conduction, convection, or radiation; the heat conduction characteristics of the food itself, the latter being related to its composition and physical characteristics such as viscosity (p. 58).

Convection heat transfer is divided into two types: free convection heat transfer and forced convection heat transfer. According to Dickerson and Read (32, p. 49), "free convection exists when the air particles move under the influence of buoyant forces due to temperature differences only." Forced convection exists when the "air particles are moved by forces other than buoyant forces due to temperature differences, such as a fan" (32, p. 49).

The calculation and measurement of heat transfer in foods were studied by Dickerson and Read (32). Thermal processing conditions, geometry of the food, and the thermal properties of the food are conditions which must be identified in order to calculate the heat transfer in food. According to the authors:

> . . . the thermal properties of the food establish how heat is distributed within a food sample. The average rate of temperature rise of the food is determined by its density and specific heat and by heat flow into the food (pp. 37-38).

Heat flow at the food surface is determined by the thermal conductivity of the food and the thermodynamic medium characteristics at the food surface. Food core temperature profiles are established by its thermal diffusivity. According to Dickerson and Read (32):

> Thermal diffusivity is a measure of the quantity of heat absorbed by a material for a given temperature change, and further indicates the ability of the material to conduct heat to adjacent molecules (p. 38).

The shape of food, or its geometry establishes relationships among volume, configuration, and surface area.

The third condition for heat transfer as described by Dickerson and Read (32) is the thermal process. Thermal processing conditions are items that cause heat transfer, which are the:

1. temperature of the heat force or heat sink,
2. initial temperature of the food, and
3. temperature difference between heat source and food surface (p. 38).

Livingston and Chang (31) determined the basic concepts of reconstituting food from a chilled condition. Reheating chilled food, according to these authorities involves "transferring to a certain mass of food (W) of a given temperature (t_1) the requisite amount of heat energy (calories or BTU) to raise the temperature to the desired serving or holding temperature (t_2)" (p. 57). The amount of energy then needed to rethermalize food from a chilled condition can be determined by the following formula:

$(t_2 - t_1)$ W x H = BTU,
where t_2 = final temp. in °F
t_1 = initial temp. in °F
W = weight of food in pounds
H = specific heat of food in BTU/lb./°F (p. 57).

Convection heating, according to Decareau (33, p. 10) is a "means of accelerating heat transfer through a fluid medium by movement of this medium. Natural convection due to thermal gradients in the air occurs in all ovens."

Forced circulation of hot air is the basic principle of forced convection ovens (31). These ovens force a stream of thermostatically controlled air over and around the food products, reheating the food in much less time than required by a conventional oven (34). According to Walker and Glew (4, p. 314), in a forced air convection oven, "heat is transferred first from the oven air to the surface of the food pack and then to the thermal centre of the pack." Walker and Glew (4, p. 314) further stated that the "main factors in the transfer of heat from the oven air to the pack surface are oven air temperature, and oven air velocity." Livingston and Chang (31, p. 58) stated that the "adequacy of performance of a forced hot air convection oven, however, is determined by the uniformity of temperature distribution achieved within the oven cavity."

A ducted-type forced air convection oven is a forced convection oven with fans built into the oven cavity with plates, baffles, and/or hot air vents designed to guide the air flow around the cavity to provide greater uniformity when heating various product types and oven loads (4) (31). Research reported by Armstrong, Dorney, and Glew (34) indicated that

> Ovens that utilize a ducted air path have a more consistent performance than those that stir the air with a fan mounted inside the oven space, because the former distribute the air over the food more evenly than do the latter (p. 96).

A method for evaluating five commercially available convection ovens for reheating pre-cooked frozen food was studied by Walker and Glew (4) at Leeds University, Catering Research Unit. A summary of the research study revealed that

> The ovens with fans external to the oven cavity and with the air flow ducted across the trays were superior to the ovens with fans built into the oven cavity. The fastest reheating was 25 min for the ducted air type and 35 min for the stirred air type. The most uniform reheating occurred in the ducted air type of ovens (p. 307).

Because of the findings, it was concluded that the ducted type of forced air convection oven was the most satisfactory convection oven for the rethermalization of frozen entrees.

Forced convection ovens were used in all of the projects at the Catering Research Unit at Leeds University, England. Ovens that utilize a ducted air path were preferred since they result in more consistent overall performance. Armstrong, Dorney, and Glew (34) developed oven design and performance criteria. The researchers determined the relationship between air velocities within a ducted air convection and standard reheat times as shown in Figure 1. According to the authors,

> The threshold velocity, above which little improvement of reheat time is obtained, is approximately eight feet per second, although higher air velocities may result in better distribution of air throughout the oven space (p. 96).

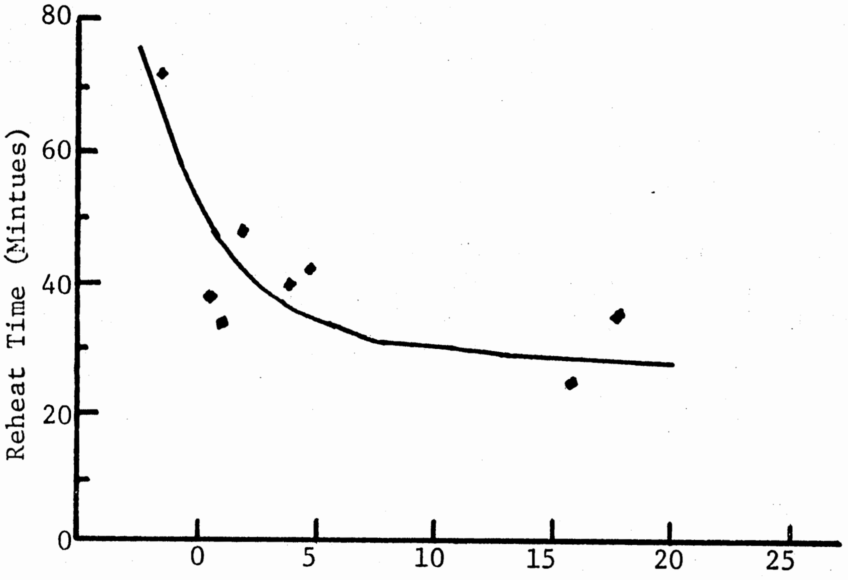

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Figure 1. Relationship of Air Velocity to Reheat Time Required in Forced Convection Ovens

An essential feature of a convection oven is its ability to transfer heat rapidly. Figure 2 shows a typical temperature curve. According to

Armstrong, Dorney, and Glew (34, p. 96), "the curve obtained by monitoring the food temperature and oven air temperature during a frozen food reheat test of a well-designed convection oven." The oven temperature falls when frozen food is initially placed into a 365°F convection oven. The oven then recovers the set temperature before the food reaches its final temperature.

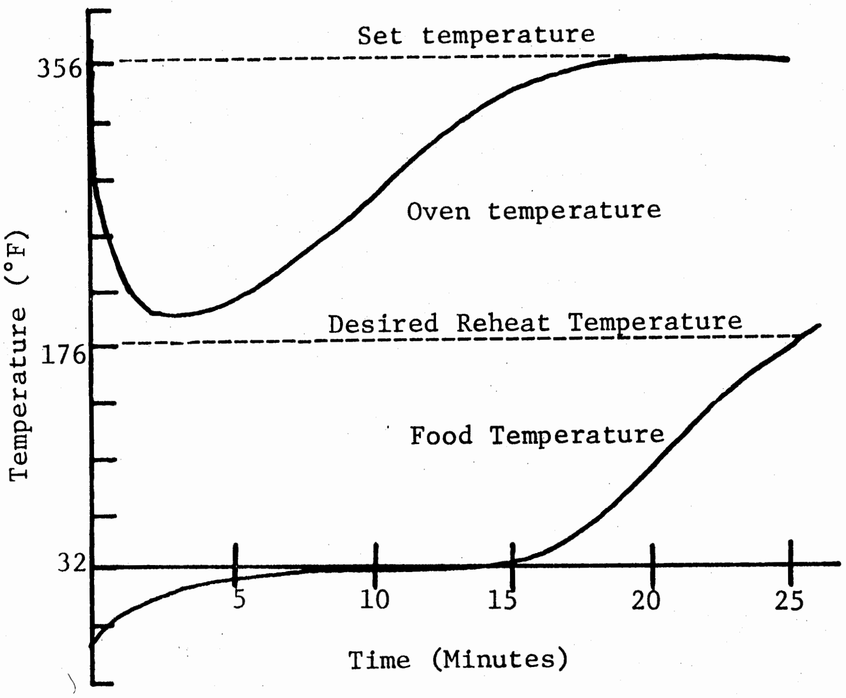

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Figure 2. Relationship of Time to Oven and Food Temperatures in a Forced Convection Oven

Food Plating, Containers, and Coverings

Even though convection oven heating is somewhat slower than other methods of rethermalization, it is fairly versatile in its application. No special plating or portioning techniques are required for foods which are heated in convection ovens, according to currently available literature. Livingston and Chang (31, p. 58) have noted that the "broadest range of products" may be reconstituted in a forced convection oven while Sell (10, p. 414) revealed that "no turning or watching are required." Unklesbay et al. (7, p. 14) suggested that "because foods may be covered when placed in a convection oven, moist and crisp foods may be heated simultaneously and maintain their desirable quality characteristics."

A wide variety of materials can be used to contain and cover foods in a forced air convection oven. The effect of the container material is small in the determination of convection heat transfer (4). An ideal package or container should be recyclable, readily disposable, or easily reusable (36).

Since convection ovens can operate at a variety of temperatures, the processing time may vary according to the packaging material used. Operating temperatures are safe for plastic pouches or trays while foods packed and covered in foil or metal containers may also be used with safety (6). Hotel china, china, earthenware, high temperature plastics, stainless steel, aluminum, and various types of oven-proof products of paper derivatives may be used in a convection oven (36) (37).

Jimenez (37) reported the performance of frozen convenience foods packaged in one and one-fourth inch deep half-size aluminum steam table pans using a microwave-convection oven. The container lid was made of foil-paperboard with oven film on the underside. Results of the study indicated that such a container and lid can be used for heating foods in microwave-convection ovens; proper microwave-convection heating of frozen foods are comparable in quality to food heated in convection ovens and conventional electrical ovens; significantly less time was required to heat frozen food by microwave-convection methods than required by either a convection oven or domestic electric oven; and, microwave-convection heating techniques need to be established for every food product to obtain optimum quality and efficiency.

Standing Time

Standing time is a factor which has not been researched in convection oven cookery. Because of the principles of forced convection heat transfer, standing time or the continued cooking after a product is removed from the oven, need not be considered when cooking food in a ducted-type forced air convection oven.

Convection Oven Research Studies

Two studies were conducted in commissary type school foodservice systems to determine temperature variability of food heated in large capacity forced air convection ovens. Convection ovens used in the studies were not a ducted-air type of oven.

Cremer and Chipley (38) studied temperatures of chili and spaghetti heated from a chilled condition in a single model convection oven. Temperatures for 72 observations of chili ranged from 34°C to 95°C and from 38°C to 98°C for 72 observations of spaghetti.

Cremer (39) examined temperature variability of spaghetti rethermalized from a chilled state in four models of electric, single cavity convection ovens. According to Cremer (39, p. 1070), "data indicated that temperature variability was a significant factor in heating food in convection ovens and that equipment model has significant influence." Cremer indicated the factors which appeared to have an effect on temperature included "oven thermostat setting, oven power rating, placement of heating elements, number of meals heated at one time, number of fans, floor or base in oven, and position of food in oven" (p. 1070). Cremer (39, p. 1070) concluded that "equipment of this type may be effectively utilized in foodservice systems but must be carefully engineered, selected, and operated."

CHAPTER III

RESEARCH PROCEDURES

The purpose in this study was to compare the cooling rate of food rethermalized decentrally in a ducted-type forced air convection oven versus a microwave oven to determine the maximum amount of time solid and liquid food can be held above 140°F. Two different shapes of institutional china plates, two china bowls, and two types of thermal plastic film were studied. The following hypotheses were tested by the study:

1. There is no significant difference in the cooling rate of mashed potatoes or of beef broth samples rethermalized in a microwave oven versus a ducted-type forced air convection oven.
2. There is no significant difference in the cooling rate of mashed potatoes or of beef broth rethermalized in a microwave oven versus a ducted-air convection oven using round or rectangular shaped plates (potatoes), two types of soup bowls (broth), or two brands of serviceware covering materials.

Type of Research

This research study is a comparative type of experimental research. The purpose of controlled experimental research is to test hypotheses about the effects or treatments on specific characteristics of the study.

The experiment was set up in a factorial arrangement of treatments having two types of ovens, two types of serviceware, and two types of serviceware covering materials. Two experiments were run. The first experiment considered solid food (mashed potatoes) and the second used liquid food (beef broth).

The experiment using the solid food was set up in a factorial arrangement of treatments having: two types of ovens (microwave oven and ducted-type forced air convection oven), two types of serviceware (round china and rectangular china), and two types of serviceware covering materials (RM-100 and Sealwrap). The experiment in which liquid food was studied had a similar set of treatment combinations, namely: two types of ovens (microwave oven and ducted-typed forced air convection oven), two types of serviceware (Hall Company china and H. F. Coors Company china), and two types of serviceware covering materials (RM-100 and Sealwrap).

The two experiments were run separately since it was known that solid foods do not cool at the same rate as liquid foods. Also, the two types of serviceware for the solid food were different than the two types of serviceware for the liquid food. The solid food experiments and the liquid food experiments used the same microwave and convection ovens. The serviceware covering materials were the same in both experiments.

This type of arrangement gave eight combinations of treatments for each food type. These eight treatment combinations were placed in the ovens in a pseudo-random order. Complete randomization of the order was not feasible due to the difference in the time required to prepare the ovens for rethermalization of the food. No more than eight food samples were processed in one day.

The plan used for carrying out each experiment required that each of the four ovens used had received two samples of food that had the same type of serviceware and serviceware covering preparation. This procedure gave 32 observations to study. The experiment for the liquid food was carried out in a manner similar to the solid food procedure.

Each of the two experiments then became a three factor factorial arrangement of treatments having duplicate measurements for each experimental unit. The difference between the response of two ovens of the same type having the same food, serviceware, and serviceware cover combination was used to estimate the experimental error.

Pre-Experimental Phase

All of the experimental work was conducted in the temperature and humidity controlled Test Kitchin at Crimsco, Inc., a foodservice equipment manufacturing firm located in Kansas City, Missouri. During the pre-experimental phase, serviceware and film types were selected, broth and potato preparation was standardized, time settings (microwave ovens) and time and temperature settings (convection ovens) were established, and experimental equipment was tested.

The researcher also determined the average temperature in an actual galley or serving area. An ambient temperature of 75°F was used in the laboratory to simulate conditions in an operating situation. This temperature was based on the researcher's past experience as well as information gathered from hospital administrators employing decentralized rethermalization.

Materials and Methods

General

A cook-chill foodservice system with decentralized rethermalization was selected for the study. This particular system was chosen because of its prevalence in modern healthcare facilities and since data pertaining to foodservice systems were either limited or unavailable. An actual operating system was simulated under temperature and humidity controlled laboratory conditions.

Ovens

Two single model microwave ovens and two ducted-type forced air convection ovens of the same model were utilized. The two ducted-type single cavity electric convection ovens were designed for heating up to 12 nine-inch round china plates or up to 18 six-inch by nine-inch rectangular plates. Two 1750 watt circular heating elements provided the heat. A blower and fan motor, combined with interior ducting, provided uniform temperature distribution of ± 10°F, throughout the heating cavity. Containers holding the food samples were placed on a movable perforated stainless steel shelf in the centermost position (center of the third shelf from the top) in the convection oven.

Two microwave ovens of the same model and manufacturer were utilized. Each oven provided 1000 watts of power in the 13 inch wide, 13 inch deep, and 7 5/16 inch high oven cavity, with a microwave frequency of 2,450 megacycles per second. Food samples were placed in the centermost area in the oven and were repositioned (180° turn) once during "standing time" to better distribute the microwave energy.

Product Characteristics

Four ounce portions of both mashed potatoes and beef broth were selected to study temperatures. This selection was based upon the frequency with which the items appear on menus in a hospital cook-chill system. Selection of the homogeneous liquid and solid samples also eliminated as much variation as possible that could occur from recording of temperatures.

Formula for preparation of the instant mashed potatoes was: Water was weighed into a stainless steel mixing bowl. Potato powder (Simplot brand) was measured into the water in the proportion of 1:7, potato powder to water (4). Potatoes were mixed according to the product instructions.

The beef broth (Lipton brand) was prepared according to the product instructions. The bulk containers of both products were covered with plastic film prior to refrigeration.

The experimental procedure simulated existing cook-chill practices where food is cooked at least one day before service and is then refrigerated at 38°F to 40°F. The following day, the bulk chilled food was portioned and covered, placed in food carts and transported to galleys located on the patient care units for rethermalization and service to patients.

Containers, Plating Procedures, and Coverings

Two types of institutional china plates were used to hold the four ounce mashed potato samples in this study. A nine-inch round plate as manufactured by the Syracuse China Company, and a six-inch by nine-inch rectangular shaped plate, manufactured by the Hall China Company, were used. The entree plates were unpatterned and white in color.

The mashed potato samples were accurately portioned onto the center of each entree plate using a four ounce spring-type scoop. The rounded back of the scoop was used to depress the center of all potato samples to be heated in the microwave oven.

A four ounce ladle was used to portion the beef broth samples into two types of china soup bowls. The seven-ounce capacity white bowls were manufactured by H. F. Coors Company and the Hall China Company.

Two brands of high temperature film were used to cover the food samples. One film, "RM-100," a 100 gauge locker film, was manufactured by the Goodyear Tire and Rubber Company while the second film, called "Sealwrap," a 50 gauge polyvinyl chloride film, was manufactured by Borden, Incorporated.

Instruments and Procedures

Final product temperatures were 165°F and 180°F (± 2°F) for the mashed potato and beef broth samples, respectively. During the pre-experimental phase, the researcher determined the specific time (microwave oven) and time and temperature settings (convection oven) necessary to rethermalize the food samples to the specific final temperature. Both the mashed potato and beef broth samples were rethermalized in the 350°F convection ovens, 20 minutes for the broth, and 25 minutes for the potato samples.

The "standing time" was considered in the determination of the specific microwave time settings for both food products. The standing time or "rest" period was 60 seconds between the cooking cycles. The product was also allowed to stand for one minute before the initial temperature was recorded. All products were repositioned 180° during the between cooking cycle to allow for more uniform heating of food. The cooking time required to heat the mashed potato samples to an internal temperature of 165°F was: heat 60 seconds; rest; and heat 10 seconds. The beef broth samples were heated 45 seconds; rest; and heated 30 seconds to obtain a final temperature of 180°F, ± 2°F.

Food temperature recordings were made through the use of an Electronic Development Laboratories model NMP pocket probe pyrometer with a three-inch long sharp needle sensor probe. The pyrometer had extremely fast sensor response time and calibration accuracy within one percent.

The pyrometer probe was positioned in the center core of each food sample as the food was removed from the ovens. The initial temperature was recorded immediately for all samples removed from the convection ovens. One minute time elapsed before an initial temperature was recorded for the microwave oven samples. The thermometer probe was not repositioned in or removed from the food and the thermal film was not removed from the serviceware during the temperature recording period.

Time was recorded by means of a Breno decimal minute stopwatch and synchronized watch. All food temperatures were recorded at two minute intervals (following the initial recording), down to and including the 140°F temperature. The time (minutes) for food to cool to 140°F was considered as the dependent variable in the study.

CHAPTER IV

RESULTS AND DISCUSSION

The purpose of this study was to determine if there was a difference in the amount of time it took to cook four ounce liquid and four ounce solid food samples, rethermalized in a ducted-type forced air convection oven and a microwave oven, to cool to 140°F. It was also determined whether the four types of serviceware (two types for each food product) and the two types of serviceware covering materials made a difference in the cooling rate of the food samples in the two types of ovens. Two null hypotheses were stated which assumed the results of the study would not reveal significant differences by or between oven types and treatments.

Two microwave ovens (oven numbers one and two) of the same manufacturer and model and two convection ovens (oven numbers one and two) of the same model and manufacturer were used in this study. The basis for testing the hypotheses was called the experimental error or duplicates in the study. The experimental error term was obtained by getting the variance between the two responses for a given oven type having the same serviceware type, serviceware covering type, and type of food (Table III, Appendix B).

Results

Table IV in Appendix B exhibits the printout of the IBM cards that were submitted to the computer for the analysis of variance by the

Statistical Analysis System (40). Results of the analysis of variance (Table V, Appendix B) showed that there were several statistically significant effects at the 0.01 level due to the treatment combinations. Significant differences ($P < 0.01$) were found in the overall mean times (cooling rates) between oven types and among food types. Significant differences ($P < 0.01$) in mean times were also found due to cover type. Finally, significant differences ($P < 0.01$) were found in the mean time between the serviceware type used to hold the liquid (beef broth) food samples (Table VI, Appendix B).

The highest overall mean time (21.222 minutes) by oven type was found in the ducted-type forced air convection oven and the lowest overall mean time (17.574 minutes) was found in the microwave oven. The highest overall mean time (20.776 minutes) by food type was found in the solid food (mashed potatoes) while the overall mean time of the liquid (beef broth) samples was 18.020 minutes. Also, the highest overall mean time by cover type was found in the RM-100 type film (19.9099 minutes) as opposed to an 18.886 minute overall mean time for the Sealwrap type of film (CB). The highest overall mean time for the liquid in the H. F. Coors soup bowl was 18.7115 minutes as opposed to 17.3292 minutes for the liquid in the Hall China soup bowl (Table VII, Appendix B).

The first null hypothesis stated that there would be no significant difference in the cooling rate of solid and liquid food samples by oven type. Differences between oven types were significant at the 0.01 level. The resulting mean cooling rate of all treatments in the ducted-type forced air convection oven was 21.222 minutes as opposed to the 17.574 minute overall cooling rate of treatments in the microwave oven. Since the F-test did indicate a significant difference between the two types of ovens, the null hypothesis was not accepted.

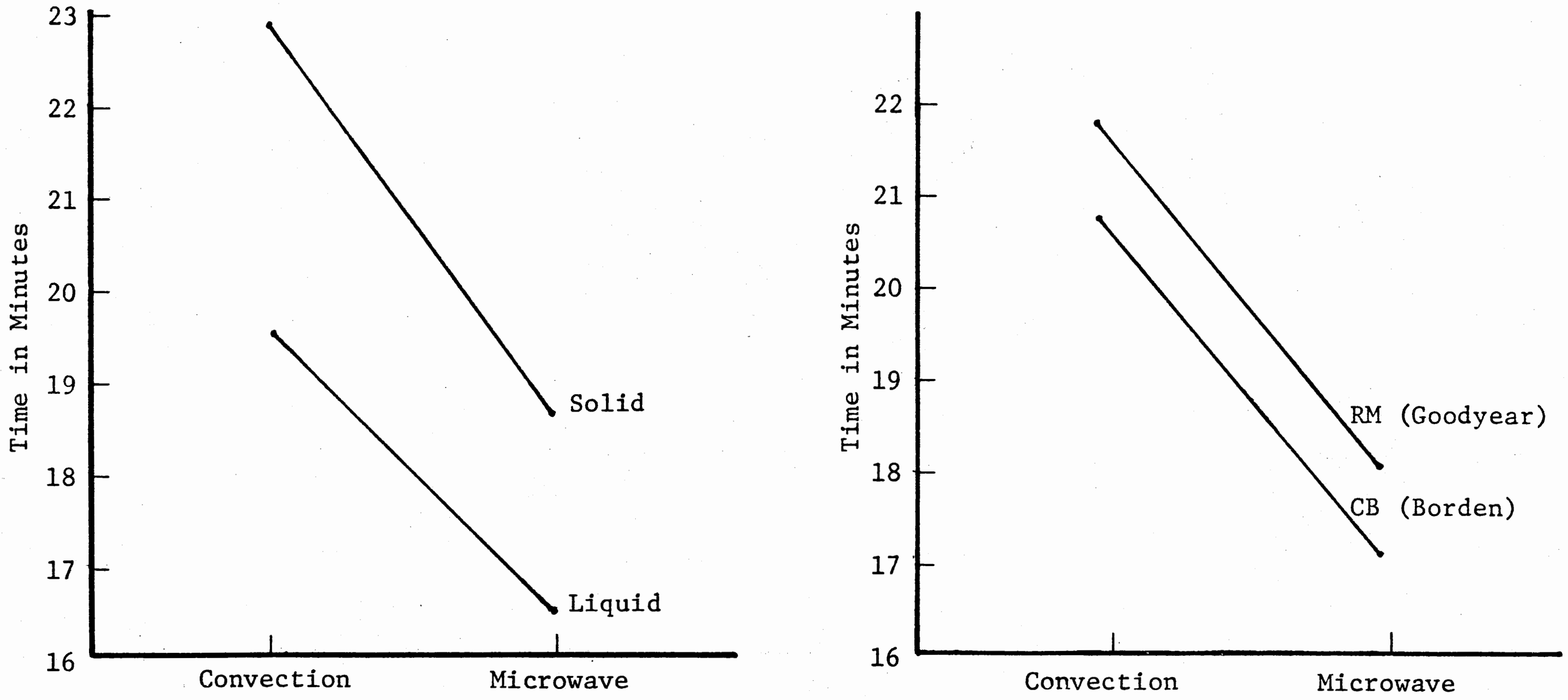
It was also found that food type was a significant factor in the overall cooling rate. Even though the liquid (beef broth) samples were rethermalized to 180°F (± 2°F), all samples cooled to 140°F in 18.020 minutes. The mashed potatoes, on the other hand, were reheated to 165°F (± 2°F), but resulted in a significantly longer cooling time of 20.776 minutes. These results were similar to the study undertaken by May (20), which revealed greater heat loss in liquids as compared to vegetables after 15 minutes time.

The pattern of cooling of the liquids and solids rethermalized by the microwave oven and the convection are illustrated in Figure 3a. The food type by oven type cooling pattern was essentially the same, as reflected by the parallel lines.

The second null hypothesis stated that there would not be a significant difference in the cooling rate due to the serviceware and serviceware covering materials utilized. Since significant differences were found by film type as well as serviceware type by food type, the null hypothesis was not accepted.

The RM-100 film demonstrated a longer cooling time (19.9099 minutes) than that exhibited by the Sealwrap thermal film (18.886 minutes). The heavier gauge RM-100 thermal film was probably responsible for such a difference.

The cover type by oven type cooling pattern is depicted in Figure 3b. The parallel lines indicated that there was no interaction due to the types of serviceware covering materials utilized.



3a. Food Type by Oven Type

3b. Cover Type by Oven Type

Figure 3. Patterns of Cooling

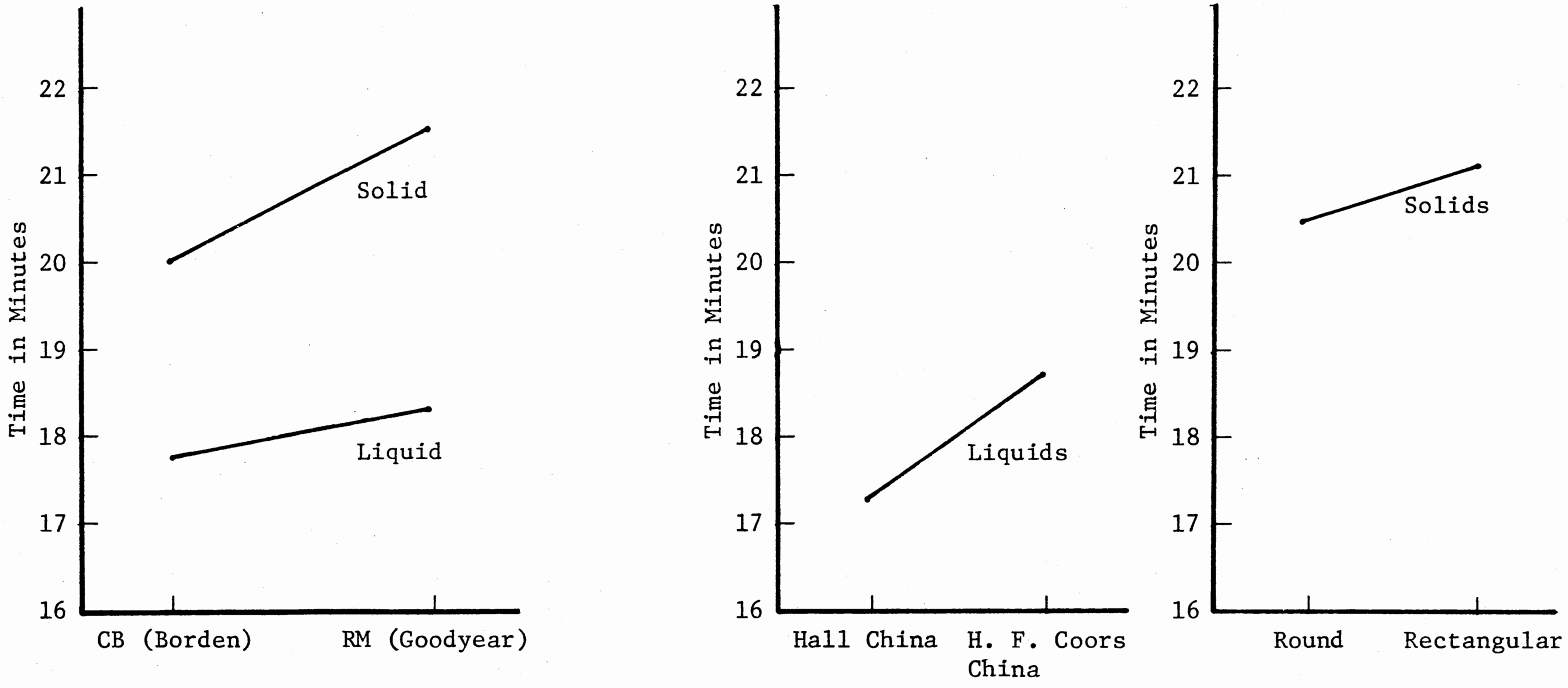
In Figure 4a, the pattern of cooling of food type by cover type is pictured. The difference in cooling time was essentially the same, regardless of the serviceware covering material utilized.

Significant mean times were found in the serviceware type within food type combination, even though the F-test calculation from the analysis of variance table did not reflect such significance. Significant differences at the 0.01 level were found in the mean time by the serviceware types used to hold the liquid (beef broth) food samples. The highest overall mean time for the liquid in the H. F. Coors soup bowl was 18.7115 minutes as opposed to 17.3292 minutes in the Hall China soup bowl. The physical size and shape of the two bowls could have resulted in the cooling rate time differences. The H. F. Coors bowl had less exposed top surface (4 7/16 inches) which tapered into a narrower base diameter (3 1/8 inches). The H. F. Coors bowl was similar in shape to the "ideal container" for use in the microwave oven (5).

The cooling pattern of serviceware type within food type are shown in Figure 4b. There was no difference in the cooling rate due to the serviceware types used to hold the solid food samples. Conversely, the cooling pattern of liquids revealed differences due to the particular types of serviceware utilized.

Discussion

There were no significant differences indicated by the duplicates employed in the study. Also, there appeared to be no interaction of treatment variables as exhibited by the following factors: food type by oven type, cover (film) type by oven type, and food type by cover type. Finally, significant cooling rate differences were not exhibited



4a. Food Type by Cover Type

4b. Serviceware Type Within Food Type

Figure 4. Patterns of Cooling

by the round and rectangular shapes of the serviceware used to rethermalize the mashed potato samples. The notion that round pans are superior to square pans, as there are no sharp corners for microwaves to become overconcentrated (5), was not a significant factor in this study. These mean times and other treatment combination mean times can be reviewed in Tables VIII and IX (Appendix B). Finally, Figures 5 through 8 (Appendix B) show the average cooling rate of solid and liquid food samples in the microwave oven and the ducted-type forced air convection oven.

Results of this study indicated that serviceware types, serviceware covering materials, menu components, and rethermalization equipment devices are factors which affect the cooling rate of food in modern foodservice systems. Consideration of such factors are important in an effort to maximize the amount of time patient-ready food can be delayed prior to consumption.

CHAPTER V

SUMMARY AND CONCLUSIONS

A hospital cook-chill foodservice system with decentralized rethermalization was simulated under controlled laboratory conditions in this study. The comparative experimental study was undertaken to determine the cooling rate of solid and liquid food samples rethermalized via a ducted-type forced air convection oven versus a microwave oven using different serviceware and serviceware covering materials. The four ounce solid food (mashed potatoes) samples were rethermalized to 165°F (± 2°F) in the two types of ovens (two ovens within each type), using two types of china plates and two types of thermal plastic film. The four ounce liquid food samples (beef broth) were rethermalized to 180°F (± 2°F) in the two types of ovens (two ovens within each type), utilizing two types of china soup bowls, and the same two types of thermal plastic film. The cooling rate of treatments within each food type and oven type combination were recorded at two minute intervals down to and including 140°F. An analysis of variance (F-test) was made to determine whether there were differences which occurred as a result of ovens, treatments, or interactions based on the decrease in the temperature of the solid and liquid foods.

Under the conditions of the present study, the following conclusions were found:

1. There were significant differences among the ovens, in regard to cooling rate of food samples. The ducted-type forced air convection oven resulted in the longest overall cooling rate, a mean time of 21.222 minutes. The shortest mean time, 17.574 minutes, was found in the overall cooling rate in the microwave oven.
2. There were significant differences in the cooling rate among the type of food. The solid food samples maintained heat more efficiently than the liquid food samples. The solid mashed potato samples had a 20.776 minute mean cooling rate as opposed to the 18.020 minute cooling rate of the liquid (beef broth) samples.
3. There was a significant difference in the cooling rate as a result of the thermal film used to cover the serviceware. The highest overall mean time by cover type was found in the RM-100 film type (19.9099 minutes) as opposed to the lesser 18.886 minute overall cooling rate for the Sealwrap type of film.
4. Significant differences were also found in the mean time among the serviceware types used to hold the liquid (beef broth) food samples. The highest overall mean time cooling rate was found in the H. F. Coors Company china soup bowl (18.7115 minutes) as opposed to 17.3292 minutes for the liquid in the Hall China Company soup bowl.

The ultimate goal of healthcare foodservice administrators is to provide patients nourishing meals of high quality, served at proper temperatures. With the advent of modern foodservice preparation and distribution systems, foodservice administrators should become aware of the numerous factors that directly and indirectly affect that goal in an effort to provide quality food served at optimum temperatures.

Recommendations for Further Study

Replication of this study using different types of food is needed. Further study is also needed to examine the microbiological characteristics according to the foodservice preparation system and rethermalization equipment devices utilized in this study. Additional study is also needed to test the difference, if any, of a ducted-type forced air convection oven versus a forced air convection oven, utilizing different gauge aluminum foil and thermal film materials. Finally, additional study is needed to examine other rethermalization equipment devices, serviceware and serviceware covering materials applicable as well as other types of food.

Trends from this study indicated that use of institutional chinaware and a 100 gauge thermal film, with rethermalization in a ducted-type forced air convection oven resulted in 21 minutes of time before food samples cooled to 140°F. When attempting to select rethermalization equipment which will minimize the loss of heat from the food, factors which contribute to retention of heat should be considered. These factors are the type of food, the type of serviceware, the serviceware covering material, the distance from the galley to the patient's room, and the holding time before service. As "the system" has yet to be engineered for healthcare foodservice operations, administrators need to optimize currently available equipment and system components.

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APPENDIXES

APPENDIX A

COOLING RATE STUDIES

TABLE I

COOLING RATE OF LIQUIDS AND VEGETABLES

	Heat Loss			
	Initial Temperature			
	Above 150°F	Below 150°F	Above 150°F	Below 150°F
Time	Liquids		Vegetables	
First 5 Minutes	23°	22°	23°	22°
Second 5 Minutes	12°	5°	13°	5°
Third 5 Minutes	8°	4°	10°	4°
Total	43°	31°	46°	31°
Transfer	10°	10°	0	0
Total Heat Loss	53°	41°	46°	31°

Source: Ernest May (20).

TABLE II

COOLING RATES AS RELATED TO SERVICE METHODS

	Time (Minutes)					
	Start	5	10	15	20	25
	Temperatures					
Potatoes						
Hot/Cold Carts	158	148	141	139	135	130
Pellet System	158	157	156	153	149	138
Soup						
Hot/Cold Carts	169	162	158	154	152	130
Pellet System	169	162	158	152	148	136

Source: David A. Gee and Boris Axelrod (21).

APPENDIX B

STATISTICAL DATA

TABLE III

EXPERIMENTAL ERROR

Source	DF	Sum of Squares	Mean Square
OvenNo(OvenType)	2	6.647092	3.323546
Cover*OvenNo(OvenType)	2	2.406988	1.203494
FoodType*OvenNo(OvenType)	2	2.660981	1.330490
Cover*FoodType*OvenNo(OvenType)	2	8.491016	4.245508
ServType*OvenNo(OvenType FoodType)	4	16.467934	4.116984
Cover*ServType*OvenNo(OvenType FoodType)	4	12.844948	3.211237
Total	16	49.844948	

Estimate of Experimental Error: $\frac{49.518959}{16 \text{ df}}$ = 3.09435 with 16 df.

TABLE IV

PRINTOUT OF IBM CARDS SUBMITTED TO THE STATISTICAL ANALYSIS SYSTEM

```
TITLE 'SHERRY ANDERSON, STUDY OF FOOD COOLING IN A HOSPIRAL, 1978';
DATA SHERI; INPUT NAME $1-8 DEPT $10-13 MODAYR 15-20 OVENTYPE $22-25 OVENNO 27
FOODTYPE $29 SERVTYPE $31-32 COVER $34-35 RUN 37 TEMP 39-41 MIN 43-44 SEC 46-47
T02 49-50 T04 51-52 T06 53-54 T08 55-56 T10 57-58 T12 59-60 T14 61-62 T16 63-64
T18 65-66 T20 67-68 T22 69-70 T24 71-72 T26 73-74 T28 75-76 T30 77-78
READS 79-80 REP 14;
TIME = (MIN*60+SEC)/60;
CARDS


   64 OBSERVATIONS IN DATA SET SHERI           30  VARIABLES

PROC ANOVA DATA=SHERI; CLASSES OVENTYPE COVER FOODTYPE SERVTYPE OVENNO REP;
MODEL TIME=OVENTYPE|COVER|FOODTYPE SERVTYPE(FOODTYPE)
SERVTYPE*OVENTYPE(FOODTYPE)
 SERVTYPE*COVER(FOODTYPE) OVENTYPE*COVER*SERVTYPE(FOODTYPE)
OVENNO(OVENTYPE) OVENNO*COVER(OVENTYPE) OVENNO*FOODTYPE(OVENTYPE)
OVENNO*COVER*FOODTYPE(OVENTYPE)    OVENNO*SERVTYPE(OVENTYPE FOODTYPE)
OVENNO*COVER*SERVTYPE(OVENTYPE FOODTYPE)
REP(OVENTYPE COVER FOODTYPE SERVTYPE OVENNO);
MEANS OVENTYPE|COVER|FOODTYPE SERVTYPE(FOODTYPE) SERVTYPE*OVENTYPE(FOODTYPE)
OVENTYPE*COVER*SERVTYPE(FOODTYPE) OVENNO(OVENTYPE)
OVENNO*COVER(OVENTYPE) OVENNO*FOODTYPE(OVENTYPE)
OVENNO*COVER*FOODTYPE(OVENTYPE)    OVENNO*SERVTYPE(OVENTYPE FOODTYPE)
OVENNO*COVER*SERVTYPE(OVENTYPE FOODTYPE);
```

TABLE V

ANALYSIS OF VARIANCE TABLE

Analysis of Variance for Variable Time		Mean	19.3981771
Source	DF	Sum of Squares	Mean Square
Oven Type	1	212.977539	212.977539
Cover	1	16.758789	16.758789
Oven Type*Cover	1	0.051567	0.051567
Food Type	1	121.504629	121.504629
Oven Type*Food Type	1	4.125977	4.125977
Cover*Food Type	1	3.414796	3.414796
Oven Type*Cover*Food Type	1	1.599171	1.599171
ServType(FoodType)	2	17.892648	8.946324
Oven Type*ServType(FoodType)	2	6.496050	3.248025
Cover*ServType(FoodType)	2	4.780773	2.390386
Oven Type*Cover*ServType(FoodType)	2	0.182300	0.091150
OvenNo(OvenType)	2	6.647092	3.323546
Cover*OvenNo(OvenType)	2	2.406988	1.203494
Food Type*OvenNo(OvenType)	2	2.660981	1.330490
Cover*FoodType*OvenNo(OvenType)	2	8.491016	4.245508
ServType*OvenNo(OvenType FoodType)	4	16.467934	4.116984
Cover*ServType*OvenNo(OvenType FoodType)	4	12.844948	3.211237
Rep(OvenType Cover FoodType ServType OvenNo)	32	100.281250	3.133789
Corrected Total	63	539.584510	8.564833

* = By.

( ) = Within or among.

TABLE VI

COOLING RATES AFTER RETHERMALIZATION AND SIGNIFICANT DIFFERENCES ACCORDING TO ANOVA SOURCE AND TREATMENT DESCRIPTION

ANOVA Source	Treatment Description	Number of Observations	Cooling Rate (Mean)	F-Calc.
1. Oven Type				
	Convection**	32	21.2223958	68.8279
	Microwave	32	17.5739583	
2. Cover				
	CB (Sealwrap)	32	18.8864583	5.4159
	RM (RM-100)**	32	19.9098958	
3. Food Type				
	Solid**	32	20.7760417	39.2666
	Liquid	32	18.0203125	
4. Serv Type Among Food Type				
	Liquid:			
	CC (Coors China)**	16	18.7114583	15.2858
	HC (Hall China)	16	17.3291667	

**Highly significant.

F $\text{Tab}_{0.01\ (1,16)}$ = 3.05.

TABLE VII

SIGNIFICANT MEANS

	Serviceware Type	N	Time
Oven Type			
Convection		32	21.2223958
Microwave		32	17.5739583
Cover			
RM-100 (Goodyear)		32	19.9098958
Sealwrap (Borden)		32	18.8864583
Food Type			
Liquid (Beef Broth)		32	18.0203125
Solid (Mashed Potatoes)		32	20.7760417
Food Type			
Liquid	H. F. Coors	16	18.7114583
Liquid	Hall China	16	17.3291667

TABLE VIII

OTHER MEANS

Oven Type	Food Type	Serviceware	Cover Type	N	Time
Convection	Liquid	CC	CB	4	20.4666667
Convection	Liquid	HC	CB	4	18.4125000
Convection	Solid	RD	CB	4	21.0958333
Convection	Solid	RT	CB	4	22.7541667
Convection	Liquid	CC	RM	4	20.1416667
Convection	Liquid	HC	RM	4	19.3416667
Convection	Solid	RD	RM	4	23.1416667
Convection	Solid	RT	RM	4	24.4250000
Microwave	Liquid	CC	CB	4	17.1000000
Microwave	Liquid	HC	CB	4	14.9791667
Microwave	Solid	RD	CB	4	18.0833333
Microwave	Solid	RT	CB	4	18.2000000
Microwave	Liquid	CC	RM	4	17.1375000
Microwave	Liquid	HC	RM	4	16.5833333
Microwave	Solid	RD	RM	4	19.6416667
Microwave	Solid	RT	RM	4	18.5333333
Convection	Liquid	CC		8	20.3041667
Convection	Liquid	HC		8	18.8770833
Convection	Solid	RD		8	22.1187500
Convection	Solid	RT		8	23.5895833
Microwave	Liquid	CC		8	17.1187500
Microwave	Liquid	HC		8	15.7812500
Microwave	Solid	RD		8	18.8625000
Microwave	Solid	RT		8	18.5333333

Key: Liquid = Beef Broth
Solid = Mashed Potatoes
CC = H. F. Coors China Company
HC = Hall China Company
RD = Round Plate (Syracuse China)
RT = Rectangular Plate (Hall China)

TABLE IX

OTHER MEANS

	Food Type	Cover Type	N	Time
Oven Type				
Convection	Liquid	CB	8	19.4395833
Convection	Solid	CB	8	21.9250000
Convection	Liquid	RM	8	19.7416667
Convection	Solid	RM	8	23.7833333
Microwave	Liquid	CB	8	16.0395833
Microwave	Solid	CB	8	18.1416667
Microwave	Liquid	RM	8	16.8604167
Microwave	Solid	RM	8	19.2541667
Cover				
CB	Liquid		16	17.7395833
CB	Solid		16	20.0333333
RM	Liquid		16	18.3010417
RM	Solid		16	21.5187500
Oven Type				
Convection	Liquid		16	19.5906250
Convection	Solid		16	22.8541667
Microwave	Liquid		16	16.4500000
Microwave	Solid		16	18.6979167
Oven Type				
Convection		CB	16	20.6822917
Convection		RM	16	21.7625000
Microwave		CB	16	17.0906250
Microwave		RM	16	18.0572917

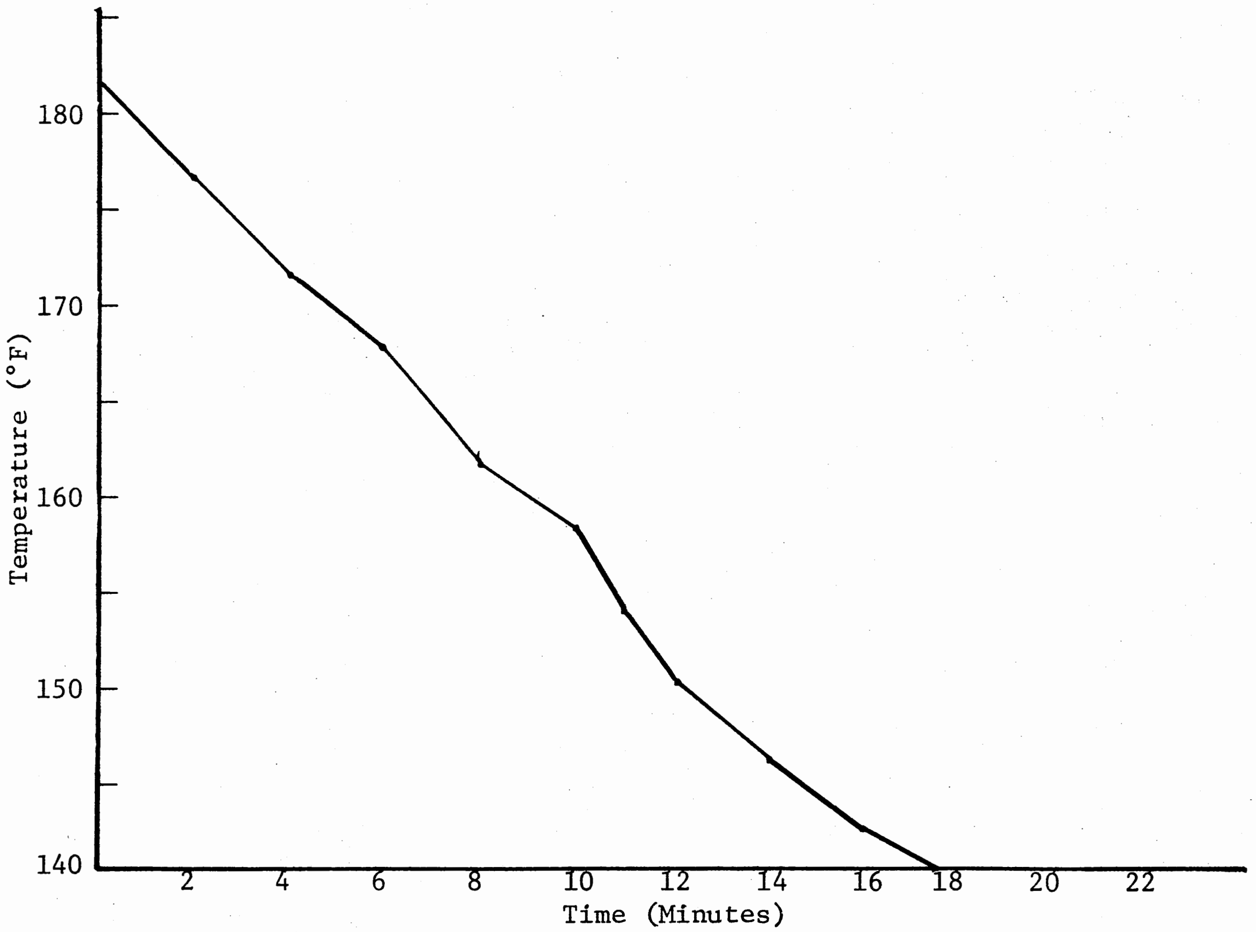

Figure 5. Liquid Cooling Rate in Microwave Oven

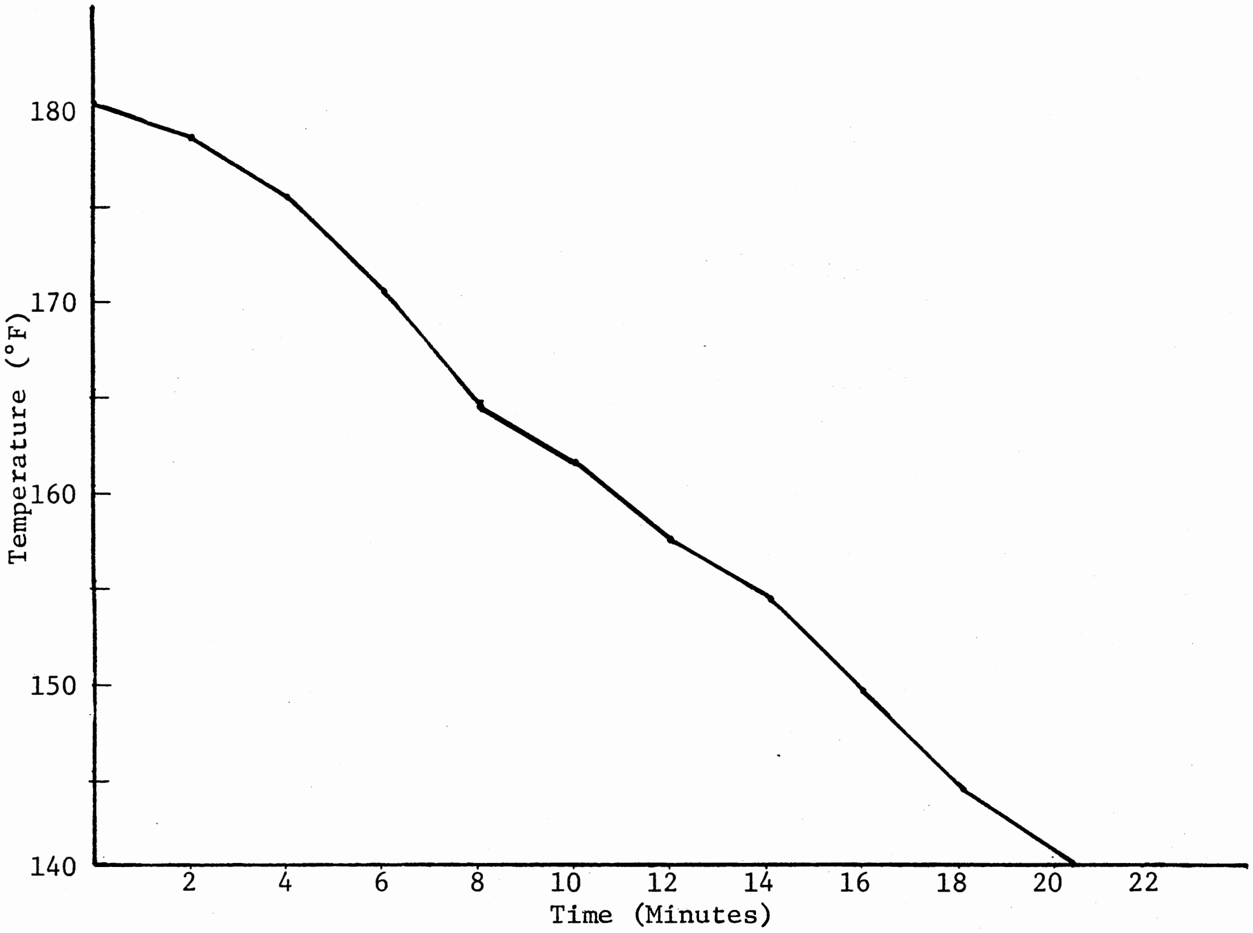

Figure 6. Liquid Cooling Rate in Ducted-Type Forced Air Convection Oven

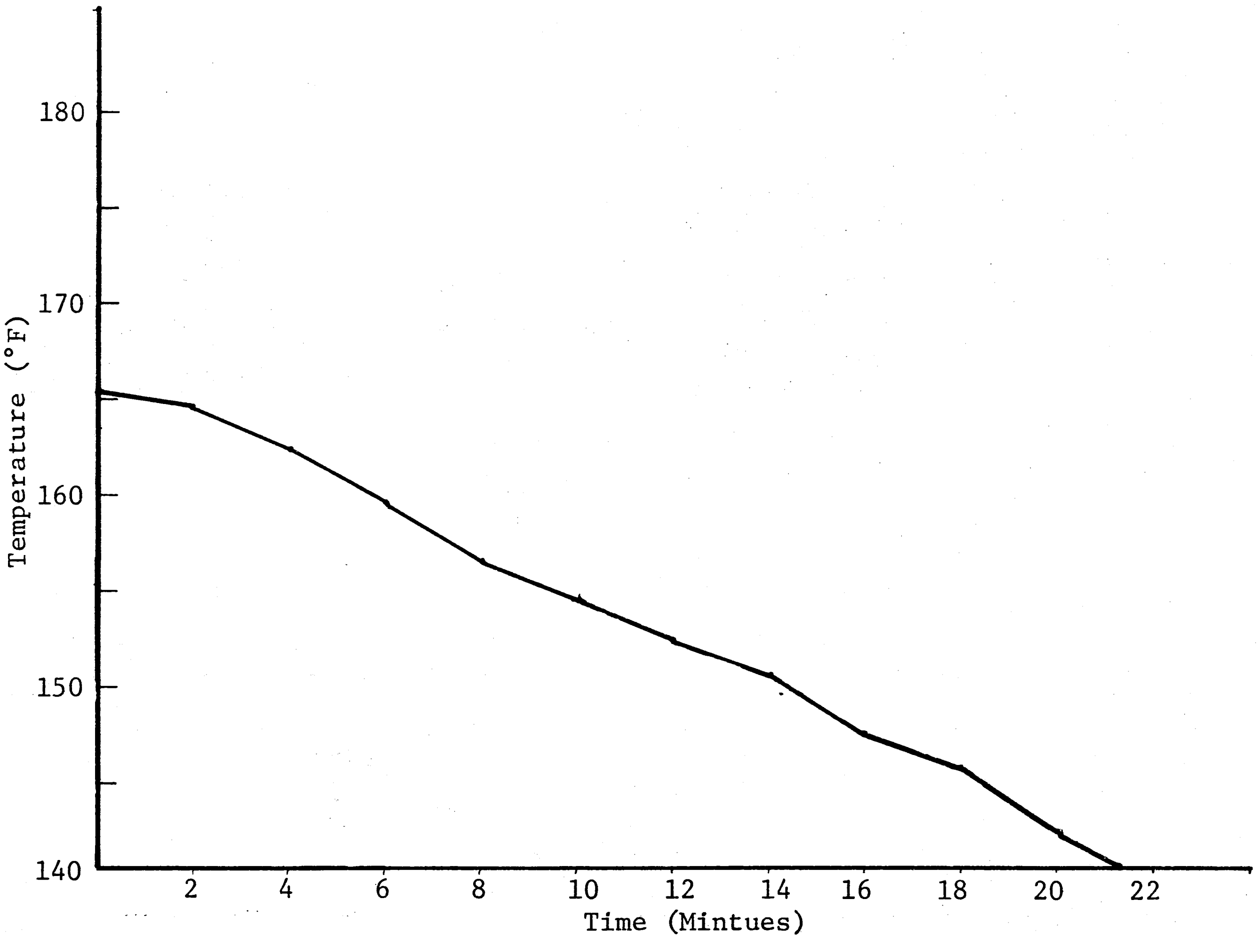

Figure 7. Solid Cooling Rate in Ducted-Type Forced Air Convection Oven

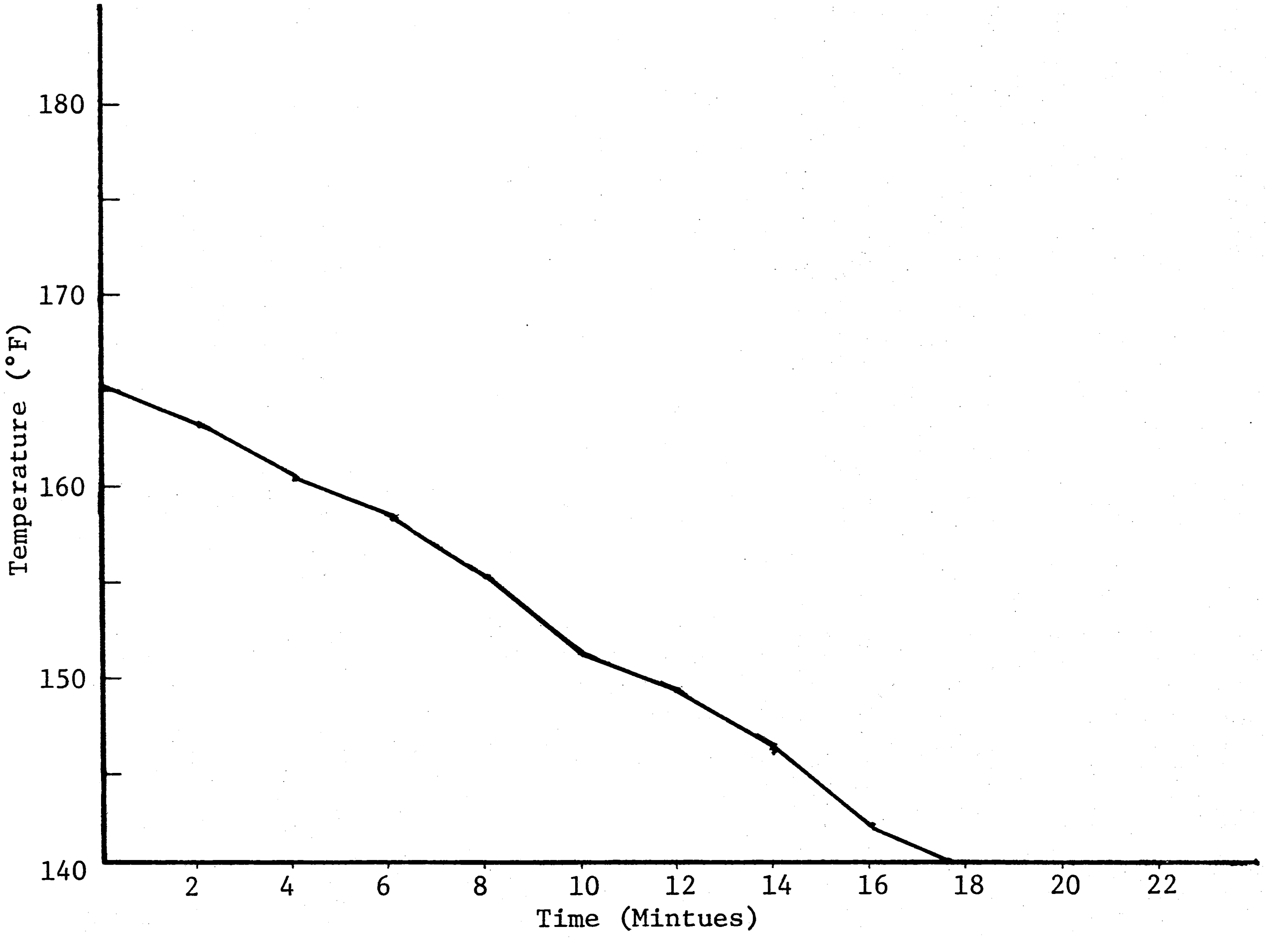

Figure 8. Solid Cooling Rate in Microwave Oven

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VITA

Sherry Jo Anderson

Candidate for the Degree of

Master of Science

Thesis: COOLING RATES OF SOLID AND LIQUID FOOD SAMPLES IN TWO RETHERMALIZATION EQUIPMENT DEVICES

Major Field: Food, Nutrition and Institution Administration

Biographical:

Personal Data: Born in South Haven, Michigan, June 19, 1951, the daughter of John and Joanne Anderson.

Education: Graduated from Kirkwood High School, Kirkwood, Missouri, in 1969; graduated from Central Missouri State University, Warrensburg, Missouri, in 1974, with a Bachelor of Science degree in Home Economics, with a major in Foods and Nutrition; received three hours credit for a correspondence course, Special Problems in Food and Nutrition, taken from the University of Idaho, Moscow, Idaho, May, 1977; attended Oklahoma State University, 1977 to 1978; completed the requirements for a Master of Science degree in December, 1978.

Professional Experience: Dietary Inservice Coordinator, Sparks Regional Medical Center, Fort Smith, Arkansas, 1974 through 1975; Supervisor of Education and Inservice Training, Crimsco, Inc., Kansas City, Missouri, from 1976 to August, 1977; Dietary Consultant for Crimsco, Inc., from September, 1977, through 1978.

Professional Organizations: Member of the American Society of Hospital Food Service Administrators.