MICROWAVE APPLIANCE PERFORMANCE AS AFFECTED BY CONTAINER GEOMETRY AND MATERIAL

by

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(ABSTRACT)

Effects of container geometry and material on microwave cooking performance, as measured by evenness of cooking, firmness, and moisture content were compared. Three food items were heated in round, tube, loaf, and square containers made of clear glass, amber glass, thermoset polyester, and polysulfone. Unflavored gelatin, custard, and cakes were prepared three times in each of the 13 microwave containers. Evenness of cooking was determined by comparing meltdown and temperature in gelatin, temperature and separation/uncooked portions in custard, and index to volume in cakes. Firmness was measured in custard while moisture content was determined in cakes. In analysis of the data, ANOVA and Duncan's multiple range test were performed.

Significant differences were found between shapes as food items heated more evenly in tube and round containers than in square containers. Food quality was affected more by shape than by material. Foods prepared in the plastic materials were more evenly heated than in the glass materials.

Statistically, shape and material interacted with each other for three measures of microwave appliance performance - temperatures and separation/uncooked portions of custards, and index to volume in cakes. The interaction of shape and material was greater as the heating time increased.

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TABLES OF CONTENTS

PAGE

CHAPTER

LIST OF TABLES

TABLE PAGE

Attention Patron:

Page __ix__ repeated in numbering

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Background of the Study

Consumer interest in convenience and saving time in food preparation has developed a market for the microwave appliance. Domestic use of microwave appliances has increased dramatically over the past decade. Pickett, Arnold, and Ketterer (1986) reported that the microwave appliance market is the fastest growing segment of the market for all major home appliances.

This growth of microwave cooking has been followed by a growth in the availability of microwave cookware. Today, a consumer can find containers of many shapes and sizes made of a variety of materials including glass, paper, and plastics.

The consumer is often confused as to what type of cookware can be used in a microwave appliance. Because the microwaves should be absorbed by the food, it is essential to use containers that transmit microwaves readily (Garrison and Brasher, 1982). Or, as Van Zante (1973) stated, containers should have a low "lossiness". Paper, plastics, glass, glass ceramic, and earthenware are all low in lossiness.

Behavior of cookware in the microwave depends on the material composition and structure, microwave power distribution, and cooking times as well as food composition and arrangement (Campanella, 1978). Today, there exists no one material that is best for all microwave cooking requirements. Consumers, therefore, must make tradeoffs.

Consumers are not always aware of the transmissivity (ability of microwaves to pass through materials) of cookware or the advantages and disadvantages of the various materials and container shapes available in the market. More importantly, for top quality food, consumers need to know which shapes and materials perform best in a microwave appliance.

Statement of the Problem

The question answered in this research was: "What effects do container geometry and material have on the cooking performance of a microwave appliance?"

The specific objectives were:

1. To compare the relationship of the shape of the container to food quality.
2. To compare the effects of container material on food quality.

These objectives were met by heating three specific food loads in a microwave appliance using round, tube, loaf, and square containers made of clear glass, amber glass, thermoset polyester, and polysulfone.

Justification

Changing lifestyles have led to a demand for time-saving appliances. The microwave appliance is meeting this demand as sales of this appliance have increased steadily over the past several years. According to the latest figures available, the saturation of microwave appliances is currently estimated to be 42.5% ("A Portrait of U. S. Appliance Industry," 1985).

As the popularity of the microwave appliance has increased, so has the demand for microwave cookware. Today, consumers have an array of shapes and materials to choose from. Available is a full line of cookware: casseroles, souffle dishes, pie plates, baking dishes, bundt (tube) pans, muffin pans, baking sheets, loaf pans, and small heat-and-serve containers made of glass, glass ceramic, or plastic.

Stehle (1979), Colato (1978), Blaha (1978), and Campanella (1978) have reported that not all microwave cookware performs the same when used for the same food preparation. Foods that are high in fat or sugar or require a long cooking time need to be cooked in containers that are heat resistant and tolerant of high temperatures. Stehle (1978) found that, when cooking foods high in fat and sugar, cookware made of thermoset polyester and polysulfone retained their shape while other plastic utensils became brittle, distorted, or cracked. Since microwave cookware performance differs, appliance consumers need to know of these differences.

Presently, a limited amount of research-based information is available to document the effect of container geometry and material on food quality. Only two studies comparing container shape have been found (Van Zante, 1961 and "Microwave Cookware," 1981). Several writers have reported comparisons of container material (Van Zante, 1961; Nassar, 1984; and Sando, Gallagher, and Rodgers, 1984).

In product literature and microwave cookbooks, manufacturers recommend the type of cookware to use in the microwave appliance. For example, writers for Union Carbide, Whirlpool, Maytag, Hardwick, and General Electric recommend the ring shape as the most efficient shape to use for cooking. The round shapes are recommended because the food is more evenly cooked than in the square and rectangular containers. These sources report that in the square or rectangular shaped cookware more energy penetrates the corners and in these areas food becomes overcooked.

Consumers have questions about cookware performance and whether shape or material make a difference in food quality. Information is needed on the effects of container geometry and material on quality of food prepared in a microwave appliance.

This type of information based on independent research is difficult for the consumer to obtain, but it is important for the consumer to be able to choose cookware that enhances microwave cooking. Therefore, the aim of this project was to provide information that may be used to help consumers make more informed choices when selecting cookware for use in microwave cooking.

CHAPTER II

THEORETICAL MODEL AND REVIEW OF LITERATURE

Introduction

The literature review explores published and unpublished literature relating to microwave cookware - geometry, material, and limitations. Information has been collected from periodicals, appliance manufacturers' publications, and telephone conversations with manufacturers' representatives as well as master's theses and other unpublished literature.

In microwave cooking, microwave radiation is absorbed by the food molecules causing molecular activity which converts the radiant energy to heat. The direction of the current flow in the electromagnetic field changes from a - to a + charge 2,450 million times per second (Blaha, 1978). The United States Bureau of Standards has adopted the term megahertz and microwaves manufactured today operate at 2450 MHz (Garrison and Brasher, 1982).

Cooking in a microwave appliance does necessitate some adaptations in cooking procedures, one of which is the type of cookware. The ideal container for microwave cooking is one that transmits the microwaves but does not absorb or reflect them. As Blaha (1978) stated, the utensil with the least amount of resistance permits the maximum amount of energy to go directly into the food. As the objective of microwave cooking is to heat food, the container chosen should allow microwaves to pass through it.

Cookware that is acceptable for use in the microwave appliance is not all the same as the transmissivity of cookware differs from one material to another. A container which readily absorbs microwave energy is 'lossy' (Van Zante, 1973). Containers, therefore, should have a low lossiness and high transmissivity. Glass, glass ceramic, paper, and some plastics are acceptable for microwave cooking (Garrison and Brasher, 1979; Colato, 1978; Campanella, 1978; Van Zante, 1973; and Pickett, Arnold, and Ketterer, 1986). The behavior of the cookware in the microwave appliance depends on the material composition and structure, microwave power distribution, and cooking times as well as food composition and arrangement (Campanella, 1978).

Theoretical Model

The model for this study divides the microwave cooking system into three sections; input, throughput, and output (Figure 1). The food load, container geometry, container composition, and input wattage are inputs to the microwave system. Throughputs represent the factors which affect food in the microwave cavity (power level, output wattage, cooking time, and placement of the load). Output represents microwave appliance performance as measured by three factors considered to be objective indicators of food quality (evenness of

INPUT →	THROUGHPUT →	OUTPUT
Load	Microwave Appliance	Performance as Indicated by Food Quality
Food	Power Level	Evenness of Cooking
Container Geometry	Output Wattage	Firmness
Container Material	Cooking Time	Moisture Content
	Placement of Load	
Input Wattage		

Figure 1 - Theoretical Model

cooking, firmness, and moisture content).

In this study, input wattage was constant and variables within the appliance were controlled. The researcher controlled the attributes of the food load but did not control container geometry and container material. Thus a comparison of food quality can be made with the container geometry and container materials.

Review of Literature

The literature review describes the input variables that affect evenness of cooking, firmness, and moisture content.

Input Variables

Food load. Food prepared in a microwave appliance often requires stirring, turning, or rotating to help the food cook more evenly. If any of these techniques are not carried out, part of the food may overcook before another part is cooked completely. Food that is not stirred, turned, or rotated will show the pattern of microwave energy distribution inside the microwave cavity.

Composition. Some foods require a shorter cooking time than others because of their composition. Foods high in fat, sugar, or moisture absorb microwaves well, which results in a shorter cooking time. The density of a food also affects cooking time as more dense foods such as meats take longer than less dense foods such as cakes (Laughon, 1980).

Quantity. As the size of the food load increases, the time required to cook the food increases. According to Van

Zante (1973), at a given power level in a microwave appliance, cooking time increases as the amount of food is increased but the relationship is not linear. For example, one potato may cook in four minutes but eight potatoes may require, not 32 minutes, but 20 minutes.

Starting temperature. Food may be placed in a microwave appliance at freezer, refrigerator, or room temperature. The lower the starting temperature of the food load, the longer the time required to reach cooking temperatures and consequently to cook.

Preparation procedure. For consistent results in a microwave appliance, food should be prepared the same way each time. If any variation occurs in the recipe, such as the amount of ingredients, starting temperature, or method of mixing, satisfactory results may not be obtained.

Container Geometry

The geometry or shape of a container also affects the heating rate of foods in the microwave appliance. Van Zante (1961) found that, when agar was used as a test material, the contents of round pans heated more evenly that did the contents of a square container. Some reference is made to shape of pan and how it affected cooking performance by writers in Consumer Reports ("Microwave Cookware," 1981). In rectangular pans, brownies, roasted chicken, cooked bacon, meatloaf, and fudge tended to be overcooked in the corners.

In both studies, overcooking in the corners of the square and rectangular baking dishes indicates high temperatures in these areas. These temperatures occur because of the absorption of more microwave energy at these areas; they were coming from the top, bottom, and two sides.

According to writers for Union Carbide ("What You Need to Know", no date) square and rectangular shaped pans, including loaf pans, can produce satisfactory results if the cookware has generous, well rounded corners at the top as well as at the bottom of the utensil. Also, the sides of the container should be as nearly vertical as possible to keep the depth and thickness of the food uniform.

A round container is better than a square or rectangular one for microwaving (Garrison and Brasher, 1982; Pickett, Arnold and Ketterer, 1986; Colato, 1978; and Van Zante, 1973). The most efficient shape is a tube or donut shape, a round container with a hole in the center (Colato, 1978). This shape permits microwaves to enter the food from the inside, outside, top, and bottom.

Container Material

A variety of cookware made from different materials is available for microwave cooking. There is no one cookware material on the market which may be used for all the foods cooked in a microwave appliance (Colato, 1978). The container material (composition) as well as color affects food quality (Van Zante, 1961; Sando et al., 1984).

Researchers writing in Consumer Reports ("Microwave

Cookware," 1981) reported that the container material (e.g., glass, ceramic, and plastic) had no discernible effect on how food cooked in a microwave. Sando et al. (1984) compared baby formula heated in several microwave appliances in plastic and glass bottles with and without caps. They found that the temperatures of liquid in glass bottles were higher than those of liquid in plastic bottles when heated for the same time. This was thought to have occurred because the glass bottle had a higher transmissivity than the plastic bottle.

Not all plastics are acceptable for use in the microwave appliance. Thermoset plastics, such as Melamine®, absorb microwave energy and should not be used. Today a wide variety of plastics are used for the manufacture of microwave cookware: thermoset polyester, polysulfone, polycarbonate, and TPX.

According to Helmreich (1985), polycarbonate is no longer being used for a base cooking material but for microwave container covers. Polysulfone and thermoset polyester are the mainstays of the plastic cookware market with thermoset polyester having a larger share than polysulfone.

Color

Color also affects the absorption of microwaves. The darker the container, the more energy is absorbed by the container. Microwaves are electromagnetic and behave in a manner similar to light rays. Since a black body can absorb

100 percent of the light that falls on it, a black body in an oven will absorb more radiant energy than a shiny one (Van Zante, 1973). Thus, colors of containers used in the microwave appliance will absorb microwaves, resulting in a container with a higher lossiness and lower transmissivity than one with no color. In support of that hypothesis, Van Zante (1961) reported that agar heated more rapidly in a microwave glass container than in a dark microwave earthenware container. Unfortunately, Van Zante's experimental design did not provide a method for separating the effects of color and material.

Input Wattage

Microwave appliances differ in their input wattage which may affect the rate of cooking because of variations in output wattage. Voltage fluctuations also can cause an increase or decrease in the output wattage of a microwave appliance. The higher the output wattage, the faster the food cooks, assuming all other factors are the same.

Summary

Since the arrival of the microwave appliance on the market, manufacturers have introduced an array of microwave cookware of various shapes and materials. It is accepted that the container geometry and material have an effect on the dependent variables: evenness of cooking, firmness and moisture content; however, no substantiating data are available.

Because manufacturers recommend round or tube shapes for even cooking, consumers need to know which containers, by geometry and material, will perform "best". Therefore, this research was designed to provide quantitative information to document the effects of container geometry and material on microwave appliance performance.

CHAPTER III

METHODOLOGY

Empirical Model

The empirical model for this study shows the independent and dependent variables (Figure 2) which are described in the following sections. Three different food loads were prepared in one microwave appliance.

Independent Variables

Food load includes the composition, quantity, starting temperature, and preparation procedure. These attributes of the food load were controlled in this study. The food loads were unflavored gelatin, baked custard, and yellow cake.

Although many shapes of cookware are available, only four container shapes were used in this study: round, tube, loaf, and square. A comparison of the cooking performance (evenness of cooking, firmness , and moisture content) of these shapes were made.

In this study, four container materials were studied: clear glass, amber glass, thermoset polyester, and polysulfone. A comparison of the cooking performance between the materials was made.

Dependent Variables

The three dependent variables measured as indicators of performance of the microwave appliance were evenness of

INDEPENDENT VARIABLES

Food Load

- a. Composition
- b. Quantity
- c. Starting temperature
- d. Preparation procedure

Container Geometry

- a. Round
- b. Tube
- c. Loaf
- d. Square

Container Composition

- a. Clear glass
- b. Amber glass
- c. Thermoset Polyester
- d. Polysulfone

DEPENDENT VARIABLES

Evenness of Cooking

- a. Meltdown
- b. Temperature
- c. Index to volume
- d. Separation
- e. Uncooked portion

Firmness

- a. Uncooked portion
- b. Separation

Moisture Content

Figure 2 - Empirical Model

cooking, firmness, and moisture content.

Evenness of cooking was measured several ways depending on the food. Meltdown refers to the amount of gelatin that melts when heated in the microwave appliance. Temperatures were recorded at various points when the gelatin and custard were removed from the microwave appliance. A higher temperature indicated a higher absorption of microwave energy.

The amount of liquid that resulted from overcooking and the amount of uncooked portion from the baked custard were measured to determine evenness of cooking. A high portion of liquid (separation) indicated overcooked areas, while a large amount of uncooked custard showed the unevenness of the microwave energy distribution. For cakes, index to volume (height) was measured as an indication of cooking performance.

In the baked custard, firmness was measured after the custard was baked. With a high reading, the food is very firm, while a low reading indicates a less firm or uncooked product.

Baked cakes were measured for their moisture content. Moisture in a cake may be due to tenderness or an uncooked area. A comparison of the moisture content of cakes baked in the different shapes and materials was made to determine the differences in cooking performances of the containers.

Design of the Study

The purpose of this study was to determine the effects of container geometry and container material on the evenness of cooking, firmness, and moisture content of food products heated in a microwave appliance. One container in each shape (round, tube, loaf, and square) and each material (clear glass, amber glass, thermoset polyester, and polysulfone) was used to prepare the three food items - unflavored gelatin, baked custard, and yellow cakes for three replications:

	Clear Glass	Amber Glass	Thermoset Polyester	Polysulfone
Round	X	X	X	X
Tube	X		X	X
Loaf	X	X	X	X
Square	X	X		

Empty cells indicate those containers not currently on the market and therefore, were not used in this study.

Hypotheses

Based on the findings of researchers using different container shapes or materials and scientific principles, the following hypotheses were formulated.

a.1. Food items will heat more evenly in the tube shaped container than in the round, loaf, or square.

a.2. Food items will heat more evenly in the round containers than in the loaf and square containers.

a.3. Foods cooked in a square or loaf container will have significantly higher temperatures in the corners than the same foods heated in round and tube containers will have along points on the perimeter.

a.4. Foods prepared in the amber glass containers will be more unevenly cooked (lower temperatures, less melting, more uncooked portions) than in containers of the other three materials.

Delimitations of the Study

Due to time and money constraints and limited availability of the containers to be studied, certain boundaries were established;

1. One brand of microwave appliance was used. This appliance was chosen as representative of the current market.
2. Each food was prepared three times in each piece of cookware.
3. The number of foods to be prepared was limited to three items chosen to be representative of foods that do not require stirring during the cooking process.
4. The number of container shapes varied by materials because not all container shapes were available in all four materials.

Limitations of the Study

Limitations of the study included:

1. Because of the inherent variation in heating patterns

of microwave appliances, the findings will apply only to the brand and model used.

2. Due to money and time constraints and characteristics of the food items that need to be used, a limited number of food items was prepared. Therefore, the findings may not be typical of findings for other foods in the same category.

3. Due to money and time constraints, a limited number of cookware shapes made of certain materials were studied. Therefore, the findings may not be typical for other shapes and materials.

Data Collection

Following a period of preliminary testing to determine cooking times and refine test procedures, the data for this study were collected in the household equipment laboratory at Virginia Polytechnic Institute and State University. Temperature in the laboratory ranged from 23°C to 30°C with an average temperature of 26°C. The relative humidity averaged 38 percent; however, it ranged from 27 to 60 percent. Barometric pressure was normally near 715 millimeters of mercury (mm) but it ranged from 710 mm to 729 mm. Composition and starting temperature of the food load were controlled as described later.

Equipment and Supplies

Appliance

The Whirlpool microwave appliance (model MW8750XP) with an input wattage of 1800W and an output wattage of 700W that was used in this study is a national brand that is typical of the type used in many homes. It has a solid state control panel and 10 power levels. Microwaves are fed into the cavity through an opening in the top, and are distributed within the appliance cavity by the use of a stirrer located at the top of the cavity. Some of the microwaves are reflected off the acrylic covered metal walls and bottom of the cavity; others travel directly to the load.

The heating pattern of the microwave appliance was determined by conducting a pastry and a custard test using procedures recommended by Quarles (Standard Test Procedures for Panasonic Microwave Ovens and Competitive Brands, no date). When the appliance shelf was covered with an 1/8 inch thick pie crust and heated for 5 minutes 6 seconds, raw areas indicating areas of low microwave concentration were found at the inside center and at a small area at the middle back of the cavity (Figure 3). This test provided an indication of the effective cooking area at the bottom of the shelf area with a low profile, high fat product.

For the custard test, nine six ounce custard cups were filled with four ounces of baked custard mixture and placed uniformly in a three x three pattern on the appliance shelf. After heating the custard for 10 minutes 17 seconds, it was found that the custard in the middle horizontal row had gelled completely, while those to the left and right were slightly gelled (Figure 4). The other six containers had no

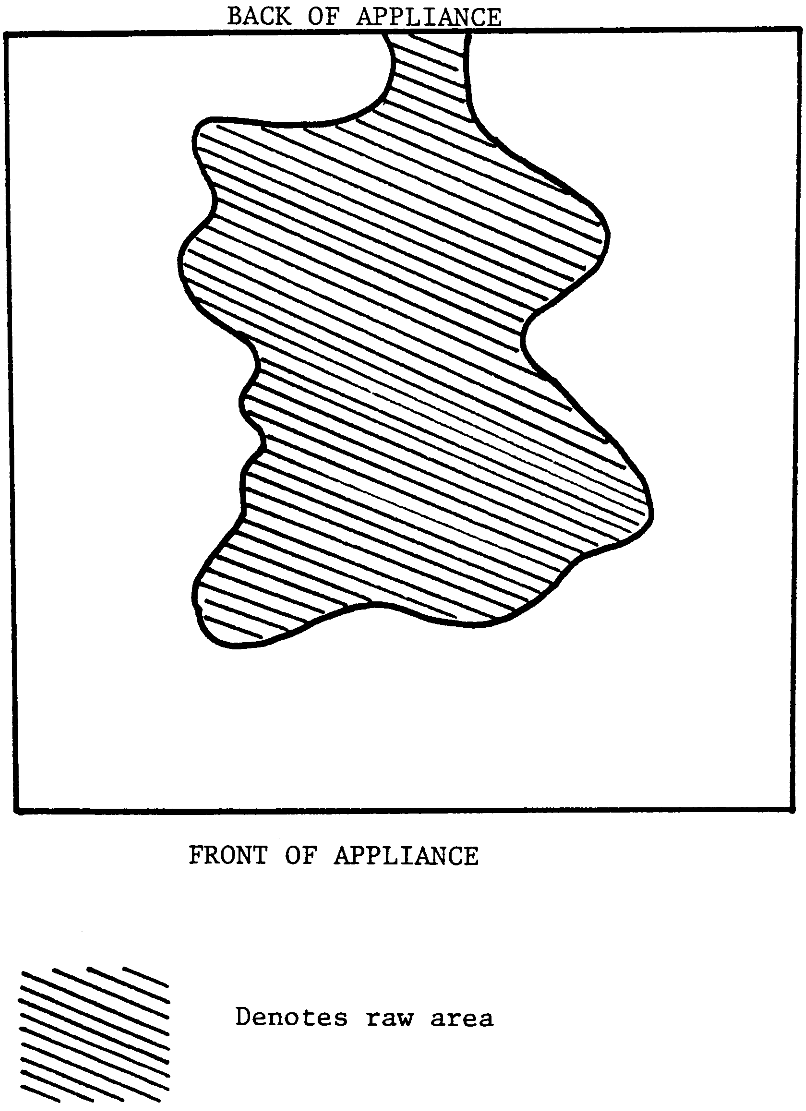

Figure 3 Pie Crust Test

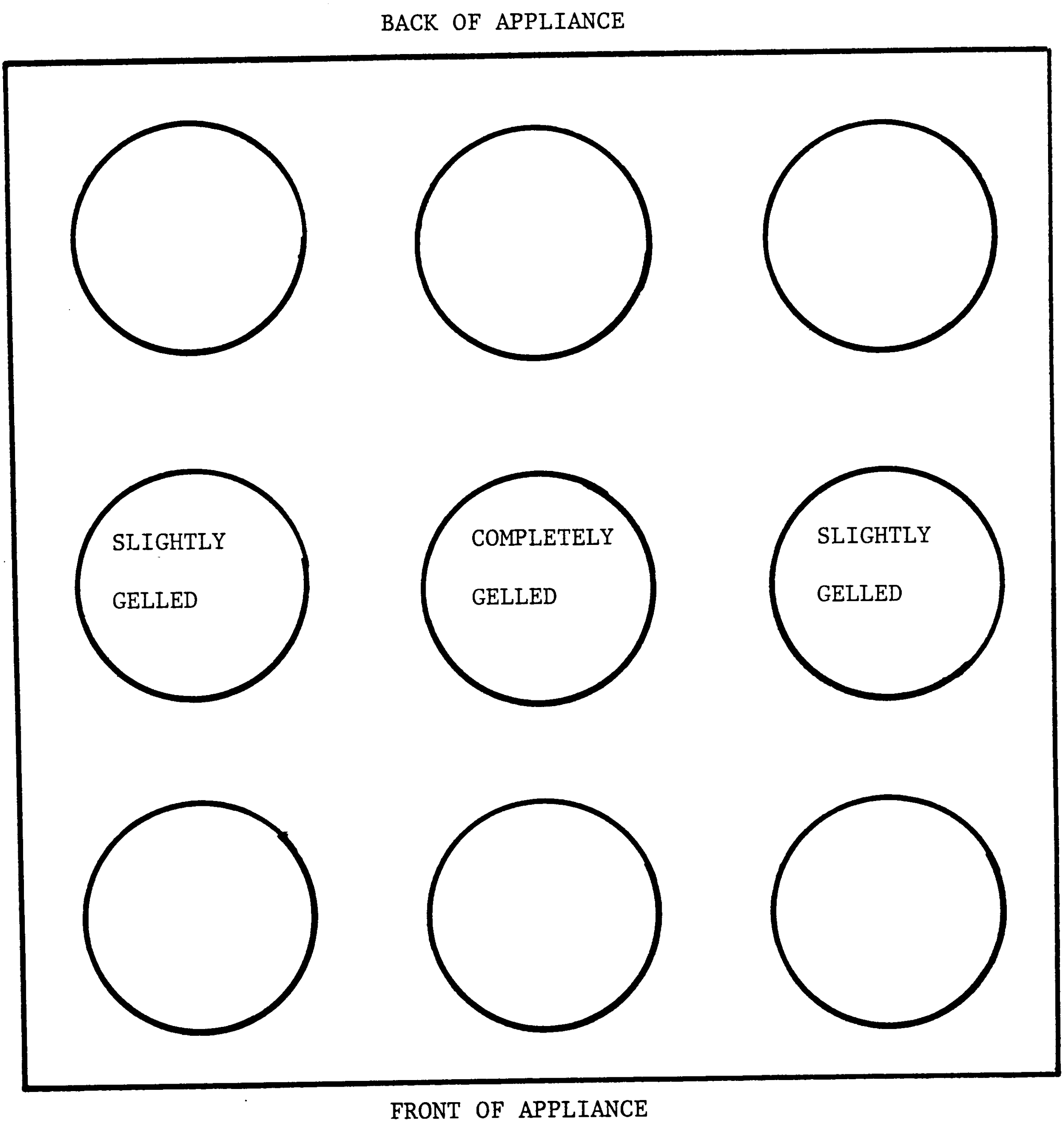

Figure 4 Custard Test

evidence of coagulation. This test is an indication of lack of cooking or cold areas in a medium profile food. These areas were measured by the different degrees of coagulation of the custard. The front and back of the microwave appliance are the cold areas in the appliance tested.

Cookware

The cookware used for this study was selected by its size, shape, material, availability, and manufacturers' guidelines for use in a microwave. Cookware shapes used were round, tube, loaf, and square containers made of clear glass, amber glass, thermoset polyester, and polysulfone. Specifications are as follows:

- Clear glass
  - 9" round baking dish, 2" deep (Fire King)
  - 8 1/2" diameter tube dish, 2" deep (Pyrex)
  - 8 1/2" x 4 1/2" x 2" loaf dish (Pyrex)
  - 8" square baking dish, 2" deep (Fire King)
- Amber glass
  - 8" round baking dish, 3" deep (Anchor Hocking)
  - 8" square baking dish, 2" deep (Pyrex)
- Thermoset polyester
  - 8 1/2" round baking dish, 1 3/4" deep (Nordic Ware)
  - 9" diameter tube dish, 3" deep (Anchor Hocking)
  - 8 1/2" x 4 1/2" x 2 5/8" loaf dish (Nordic Ware)

Polysulfone

8 1/2" round baking dish, 2 1/2" deep (Tara)

8" diameter tube dish, 3" deep (Tara)

8 1/4" x 4 1/2" x 2 5/8" loaf dish (Tara)

Food Items

The three food products that were used in this study were representative of foods cooked in a microwave appliance that do not require stirring. These included unflavored gelatin, baked custard, and yellow layer cakes. Each of the three food items was prepared three times in each container.

The quantity of food in each load was the same for each container. The amount of food used in each container was based on quantities recommended by microwave cookbooks and food package labels. For unflavored gelatin, one package of gelatin was dissolved in 574 ml of water. The custard was prepared using a standard microwave recipe that made 700 ml of uncooked custard. The amount of cake batter used was based on recommendations from food package labels and microwave cookbooks.

Because the same amount of food load was used in each test container, the depth of the food load varied with the container. Loaf containers had a higher depth of food than did the round, tube, or loaf containers. The square containers had the lowest depth of food load.

Variables and Measures

Standard laboratory instruments were used to measure the enviromental factors and dependent variables (Table 1). The instruments that were used to measure the environmental variables of temperature, relative humidity, and barometric pressure were a thermometer, psychrometer, and barometer, respectively. Dependent variables included the evenness of cooking, firmness, and moisture content of the food load. Evenness of cooking in the gelatin was measured in degrees Celsius with an instant reading thermometer at designated points on each container as described in Appendix A. After heating, the melted gelatin was poured into a glass funnel that was plugged with glass wool and placed inside a graduated cylinder. The amount of meltdown (melted gelatin) was measured in milliliters. The gelatin drained for one minute so that room temperature would not affect melting.

The evenness of cooking in the custard was measured using an instant reading thermometer to record food temperatures at designated locations (Appendix A). Next, readings for firmness were taken at the same locations as temperatures using a penetrometer with an aluminum compression disc attachment 2.5 cm in diameter. To measure the separation of liquid in the custard or uncooked portion of the custard, the cooked custard was poured into a National Bureau of Standards sieve of nine meshes per inch with catch pan and allowed to drain for two minutes. Then the drained liquid was poured into a graduated cylinder and measured in milliliters.

Table 1

Instruments Used to Measure Environmental and Dependent Variables[1]

Variable	Instrument	Measurement Unit
<u>Environmental</u>:		
Temperature	Thermometer	Degrees Celsius
Relative Humidity	Psychrometer	% Relative Humidity
Barometric Pressure	Barometer	mm Mercury
<u>Dependent</u>:		
Food Quality		
1. Evenness of Cooking		
a. Temperature	Instant Reading Thermometer	Degrees Celsius
b. Meltdown	Graduated Cylinder Glass Wool Funnel	Milliliters
2. Index to Volume	Vernier Caliper	0.1 cm
3. Firmness	Penetrometer	0.1 mm
a. Uncooked portion	Graduated Cylinder	Milliliters
4. Moisture Content	Brabender Moisture/Volatile Tester	% Moisture

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[1] The independent variables were container geometry (round, tube, loaf, and square) and container material (clear glass, amber glass, thermoset polyester, and polysulfone.

An index to volume of yellow cakes was measured in terms of height as measured with a vernier caliper at eight points on the tube containers and five points on each of the other shapes (Appendix A). Index to volume was measured to determine the extent of thermal setting of the batter structure. The thermal setting is dependent on the temperature of the gelatinization of the starch in the structure. A higher temperature seems to indicate that a more rapid coagulation of cake batter in relation to the rate of gas formation and gas expansion prevents the collapse of cells. Index to volume (height) was an indication of the effect of temperature in that location on the thermal setting of the batter (Bennion, 1985).

Moisture content of cakes was measured by drying 10 gram samples to a constant weight in a Brabender moisture/volatile tester at 140 °C (Appendix A). Samples were taken from the cake by using a stainless steel one inch corer to cut uniform samples from eight locations for the tube shape and five for the other shapes.

General Procedures

The procedures and quantities that were followed are based on those suggested in manufacturers' recipes, the use and care guide for the microwave appliance, instructions on the food package labels, and preliminary testing conducted to establish precise procedures.

In order to minimize uncontrollable effects, the order of the cookware to be tested was randomly selected. The geometry/material of each container was written on a separate piece of paper and placed in a bowl. A container was selected from the bowl and replaced with a blank slip of paper. All papers were drawn until all containers were selected for one replication. This process was repeated twice to complete the randomization for the three replications. To facilitate purchase and storage of supplies and use of instruments, the same food item was tested until all replications were completed.

Procedures were standardized as nearly as possible. Specific procedures for each test are given in Appendix A. The microwave appliance was turned on as soon as the food item was placed in the appliance and the door was closed. Operating time of the appliance was monitored with a stop watch and controlled to the nearest .01 minute.

A data sheet was completed for each of the three food items (Appendix B). Information recorded on the data sheet included the variables that were measured and environmental factors that were monitored. Ambient temperature, relative humidity, and atmospheric pressure were recorded before each test was conducted.

For each test, the geometric center of the container containing the food item was placed in the geometric center of the shelf of the microwave appliance. A template that covered the shelf and had the shape of the container cut out of the geometric center facilitated placement of the container in the geometric center of the shelf (see Figure 5). This template was removed before heating began. In addition, containers were oriented the same way in the microwave appliance for each replication. Each container was marked with a reference point to designate the back of the microwave cavity. When placed in the microwave appliance, this point was positioned facing the back of the cavity.

The refrigerated gelatin was heated in the microwave appliance at 100% power for one minute while the custard was heated for 11 minutes at 50% power. After mixing the cake, the batter was poured into a test container, placed in a microwave appliance, and heated for eight minutes at 70% power. Templates were used to determine the points for measuring temperature, firmness, and index to volume in each of the containers (see Figure 6).

After heating, a stainless steel cylinder one inch in diameter and 3 1/2 inches high (a corer accessory for the Warner-Bratzler Shear instrument) was used to cut samples from the same area of each cake so that in data collection the same areas were being measured. When the baked cake was removed from the test container, it was placed on a premarked plate to make sure that the measurement locations were the same for each test.

Data Analysis

To compare characteristics of the three food items

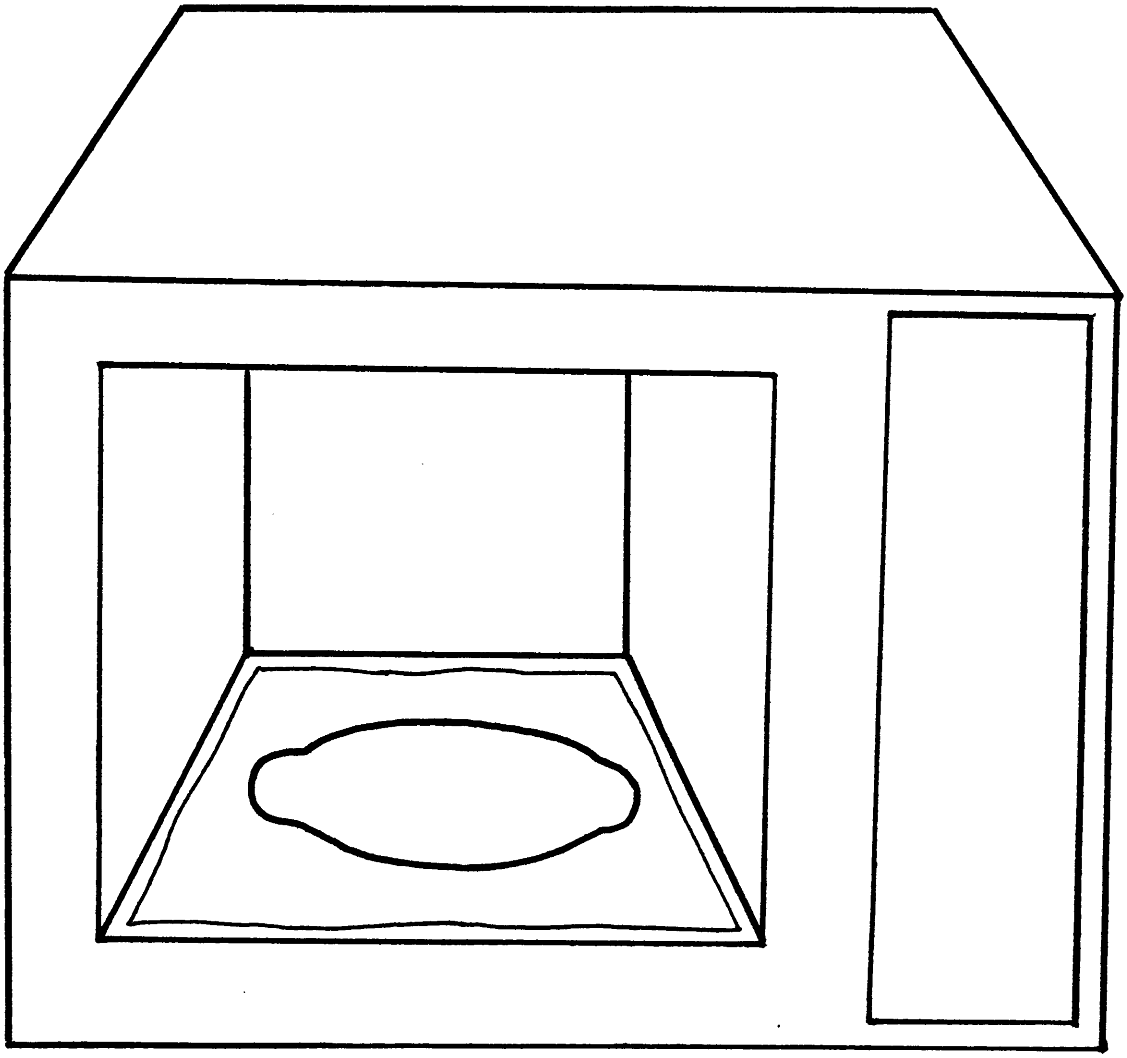


Figure 5 Template on Bottom Shelf

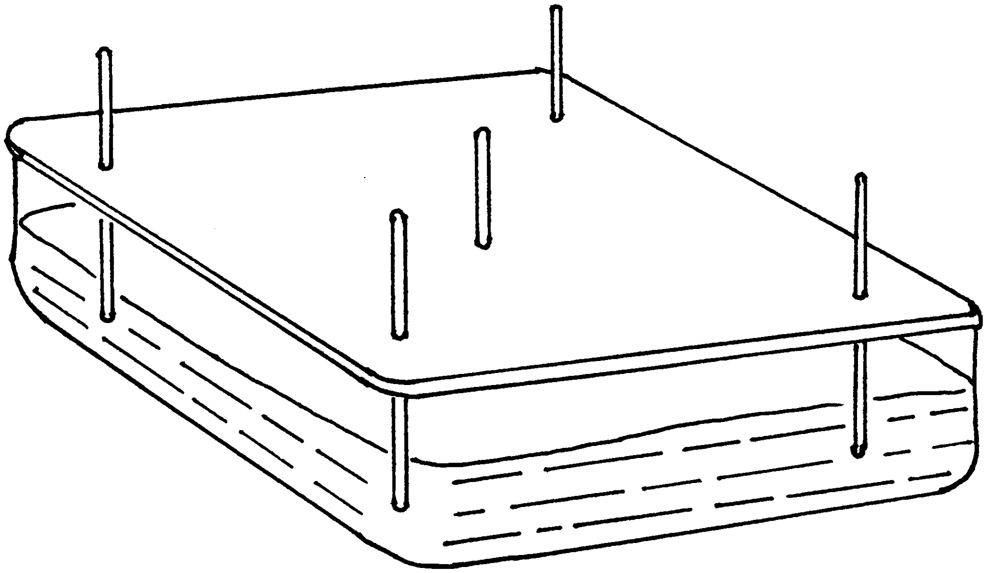


Figure 6 Template on Test Container

different materials, several calculations were used:

1. The means, ranges, and standard deviations were computed using information for the three replicate tests conducted with each food item in each container.

2. Analysis of variance (ANOVA) was computed to compare the means of the variables for the food prepared in the same material but different shape container and the same shapes but different materials. If the differences were statistically significant ($p < 0.05$), Duncan's multiple range test was performed.

3. ANOVA and Duncan's Multiple Range test were used to compare the differences among the variables for the three food items prepared in the same material but different shape container and the same shapes but different materials and determine the interaction between shape and material.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The performance of a microwave appliance was compared when round, tube, loaf, and square containers made of clear glass, amber glass, thermoset polyester, and polysulfone were used for heating three food items. Each food item was prepared three times in each container. Evenness of cooking was measured by objective tests to compare temperatures in gelatin and baked custard; meltdown in gelatin; separation/uncooked portion in baked custard; and index to volume in cakes. Firmness in baked custard and moisture content in cakes was determined by using a penetrometer and Brabender moisture/volatile tester, respectively. (Specific results for food quality resulting from tests with each shape and material are in Appendix C.)

In this chapter are presented the results in terms of each container by material and geometry and a discussion of the results. Each section is focused on an independent variable, either container geometry or container material, and includes the general and specific findings for each food item. Results of the statistical procedures are given. The statistical significance level was set for all tests a priori at 0.05. Then the findings are related by independent variable, geometry or material, to hypotheses tested.

Data are not available for all cells because some container shapes were not available in all four materials. The same points (A-E or A-H) were used to measure temperature, firmness, index to volume, and moisture content (Figure 7). On the round, loaf, and square shapes, points A-E referred to;

A (UL) - upper left position (corner), 1 inch from edge
B (UR) - upper right position (corner), 1 inch from edge
C (LL) - lower left position (corner), 1 inch from edge
D (LR) - lower right position (corner), 1 inch from edge
E (C) - geometric center of container

The tube shape containers had eight measurement locations which included:

A (UL) - upper left position (corner), 1 inch from edge
B (UR) - upper right position (corner), 1 inch from edge
C (LL) - lower left position (corner), 1 inch from edge
D (LR) - lower right position (corner), 1 inch from edge
E (IL) - inside center left position, 1 inch from inside edge
F (IB) - inside top position, 1 inch from inside edge
G (IR) - inside center right position, 1 inch from inside edge
H (IF) - inside bottom position, 1 inch from edge

GEOMETRY

Gelatin

Means for the temperatures and meltdown for the four

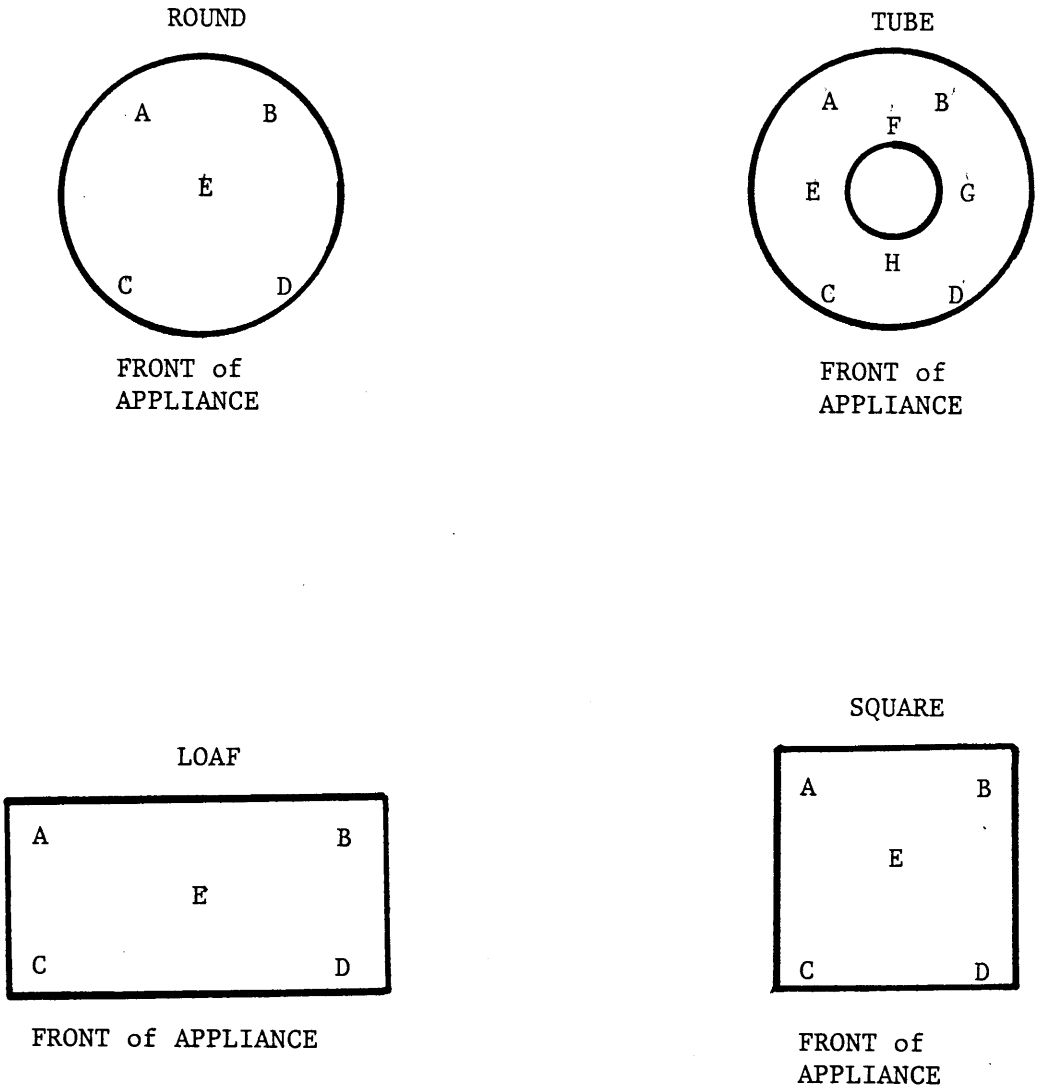


Figure 7 Measurement Points on Test Containers

shape containers are listed in Table 2. Point E had the lowest temperature point for the round, loaf, and square shapes. This location is unique from the other points because it was the geometric center for these shapes. The highest temperature point was D (LR) for the round, tube, and loaf shapes. In the square shape, A (UL) and C (LL) were the highest points.

The means of the loaf containers for the five temperature points (A-E) were significantly different from the other three containers. This shape container had higher perimeter temperatures and lower center temperature than the other three containers. The square container was significantly different at temperatures B (UR) and D (LR) from all shapes, at temperature C (LL) from the round and loaf, and at temperature E from the loaf shape.

Round shapes were not significantly different at A (UL), B (UR), and D (LR). Temperature C (LL) was significantly different from the square and tube , and temperature E was significantly different from the loaf. The tube shape was significantly different from the round and loaf shapes at temperatures B (UR). No comparison is made between E on the tube shape and E on the other shapes because the two locations are not the same; E is the geometric center for the round, square, and loaf shapes and one inch from the inside tube on the right side for the tube shape.

Temperature was directly related to the location of the

TABLE 2

Means for Three Replications of Gelatin Temperatures and Meltdown by Container Geometry

	Round	Tube	Loaf	Square
Temperature (C)				
A (UL)	29.00^{b}	30.22^{b}	31.50^{a}	29.33^{b}
B (UR)	29.67^{b}	29.45^{b}	32.17^{a}	27.50^{c}
C (LL)	30.17^{ab}	28.22^{c}	30.92^{a}	29.33^{c}
D (LR)	30.42^{b}	30.67^{b}	32.17^{a}	29.00^{c}
E[1] (C)	19.00^{b}	24.89^{a}	16.83^{c}	19.33^{b}
F[2] (IB)	---	24.33	---	---
G[2] (IR)	---	28.44	---	---
H[2] (IF)	---	24.78	---	---
Meltdown(ml)	217.92^{a}	202.22^{a}	202.92^{a}	167.50^{b}

[a,b,c] Means with different letters (a,b,c) in the same horizontal row are significantly different ($p < 0.05$) using the Duncan multiple range test.

[1] For the tube shape, E was located at the inside left (IL) while for the other shapes E was at the geometric center.

[2] No comparisons were made of these points; round, loaf, and square shapes do not have these points.

temperature point on the test container. For the square and loaf shapes, points A-D were located one inch from the corners while A-D for the round and tube shapes were one inch from the outside edge of the container. The raw data indicate the temperatures at the corners of the loaf and square were higher although the results were not significantly different. The loaf container had the lowest temperature at E(C), 16.83 °C, compared to the round, 19.00 °C, and for square, 19.33 °C.

Meltdown (a measure of evenness of cooking) was significantly different in the square container from the round, tube, and loaf containers but those three did not differ significantly from each other. The amount of meltdown (melted gelatin) for the round shape was 167.50 milliliters, 20.7% less than the tube and loaf and 30% less than the round shape.

In conclusion, the geometry of the container did affect cooking performance as measured with gelatin as the loaf container had higher corner temperatures than the round and tube containers. Although the square shape did not have significantly different temperatures in the corners than the tube and round, meltdown was significantly less because the gelatin heated more unevenly in the square container.

<u>Custard</u>

In general, temperature of the custard was directly related to the shape of the container, and all shapes were significantly different from each other. The round and tube shapes had consistently even temperatures throughout the product (Table 3). Custard temperatures for the round shape were fairly even at the five temperature points, from 64.12 °C to 68.42 °C. This trend was found in the tube shape also with a temperature range of 72.11 °C to 77.44 °C.

The loaf shape had significantly higher temperatures in the corners and in the center while the square shape did not. The center temperature of the custard (55.0 °C), heated in the square shapes, was the lowest of the three shapes with E at the geometric center where the this temperature was significantly different. In the square shape the significantly different mean at A (UL) can be attributed to the square amber container which, for two replications, had no readings. The custard at this point produced a large air bubble and burst before it was finished cooking pushing the custard away from the measurement point.

The firmness of the custard was affected by the shape of the container. The square containers were significantly different from the other shapes for all firmness readings except location B (UR). The custard was more firm at A (UL), C (LL), and D (LR) and less firm at E (C). The firmness mean for A (UL) in the square shapes is low because the custard in the square amber glass container was forced away from the point when a large air bubble burst before cooking was completed. This occurred for two replications and no firmness

TABLE 3

Means for Three Replications of Custard Temperatures, Firmness, and Separation/Uncooked Portions by Container Geometry

	Round	Tube	Loaf	Square
Temperature (C)				
A (UL)	65.33^{b}	74.79^{ab}	80.42^{a}	39.17^{c}
B (UR)	68.42^{c}	75.89^{b}	83.17^{a}	58.67^{d}
C (LL)	66.25^{c}	72.11^{b}	80.67^{a}	61.67^{d}
D (LR)	67.67^{c}	74.33^{b}	81.03^{a}	61.17^{d}
E[1] (C)	64.12^{c}	75.44^{b}	79.08^{a}	55.00^{d}
F[2] (IB)	---	74.78	---	---
G[2] (IR)	---	77.44	---	---
H[2] (IF)	---	74.11	---	---
Firmness (mm) in compression				
A (UL)	34.33^{a}	39.56^{a}	30.00^{a}	15.00^{b}
B (UR)	29.08^{ab}	37.11^{a}	22.42^{b}	24.33^{ab}
C (LL)	32.25^{a}	39.56^{a}	31.08^{a}	16.33^{b}
D (LR)	34.75^{b}	30.44^{d}	40.42^{c}	17.83^{a}
E[1] (C)	90.67^{c}	43.11^{b}	90.67^{a}	171.50^{d}
F[2] (IB)	---	40.22	---	---
G[2] (IR)	---	31.78	---	---
H[2] (IF)	---	61.45	---	---
Separation/ Uncooked (ml)	17.67^{b}[4]	4.33^{c}[3]	7.40^{c}[3]	49.50^{a}[4]

[a,b,c,d] Means with different letters (a,b,c,d) in the same horizontal row are significantly different ($p < 0.05$) using the Duncan multiple range test.

[1] For the tube shape, E was located at the inside left while for the other shapes E was at the geometric center.

[2] No comparisons were made of these points; round, loaf, and square shapes do not have these points.

[3] Liquid resulting from syneresis.

[4] Liquid resulting from uncooked portion.

readings could be taken. The firmness at the center of the square containers was 47% less than in the round and loaf shapes. The mean firmness of E (C), 90.67mm, was the same for loaf and round shapes. For the shapes with E at the geometric center - round, loaf, and square - the firmness was significantly less than the other firmness measurements.

Separation or uncooked portions of the square and round shapes was determined to be significantly different from the other shapes. The square shape had a mean of 49.50ml of liquid from uncooked custard compared to 17.67ml of liquid from uncooked custard for the round shapes.

The tube and loaf containers had 4.33ml and 7.40ml of separation liquid resulting from syneresis which is the separation of water from the gel (Bennion, 1985). These results were significantly different from each other and with the other shapes. Visual observations determined if the measured amount was due to separation or uncooked custard. Cloudy liquid indicated separation, while liquid custard indicated uncooked custard.

Yellow Cakes

The height of yellow cakes was measured in centimeters to determine index to volume. Because depth of batter in the containers varied among shapes, no comparison of height was made between shapes.

Moisture content was different for the four shapes of cakes when moisture content was assessed by drying 10 gram samples in a Brabender moisture/volatile tester. The round and square shapes were significantly different in moisture content than the loaf (Table 4). The round and square cakes tended to be more moist than the loaf shapes. Only at D (LR) was the square cake less moist than all other shapes. Significant results were not found for the tube shape except at B (UR) which was different than the round and square shapes.

Hypotheses Related to Geometry

There were three hypotheses related to the geometry of the container. First, it was hypothesized that food items would heat more evenly in the tube shape than in the round, loaf, and square shapes. For the gelatin test, the temperature and meltdown of the gelatin heated in tube containers were not significantly different from the other three shapes. With the custard, the temperature and separation/uncooked portions were significantly different for the tube containers but significant results were not found for firmness except between the tube and square with the tube heating more evenly than the square. Tube shapes were not found to be significantly different than the loaf shapes in the comparison of moisture content. On the average, the tube shape was not significantly different from the round and loaf but was significantly different from the square. The hypothesis was rejected for the round and loaf shapes but retained for the square shape because the tube shape did not

TABLE 4

Means for Three Replications of Moisture Content in Cakes by Container Geometry

	Round	Tube	Loaf	Square
Moisture Content (%)				
A (UL)	28.07^{a}	26.49^{ab}	25.03^{b}	27.43^{a}
B (UR)	28.00^{a}	26.22^{b}	25.81^{b}	29.08^{a}
C (LL)	27.95^{a}	27.39^{a}	25.21^{b}	27.02^{a}
D (LR)	26.22^{a}	26.57^{a}	25.06^{a}	21.50^{b}
E[1] (C)	30.13^{a}	27.04^{b}	27.34^{b}	30.73^{a}
F[2] (IB)	---	24.26	---	---
G[2] (IR)	---	27.00	---	---
H[2] (IF)	---	28.76	---	---

[a,b] Means with different letters (a,b) in the same horizontal row are significantly different ($p < 0.05$) using the Duncan multiple range test.

[1] For the tube shape, E was located at the inside left while for the other shapes was at the geometric center.

[2] No comparisons were made of these points; round, loaf, and square shapes do not have these points.

heat food more evenly in the round and loaf shapes but did heat the food more evenly than the square shape.

Secondly, it was hypothesized that round shapes would heat food items more evenly than the loaf and square containers. On the average, the temperatures of the gelatin in the round shapes were not significantly different than in the other shapes. This significant result was also found for the meltdown of the gelatin. When custard was heated in the different shape containers, a significant difference was found between round and square shapes for the three measured food variables. No difference was found between round and loaf containers. Moisture content of cakes prepared in the round shape was significantly higher than that of cakes in the loaf shape but not significantly different from that of cakes in the square containers. Therefore, the hypothesis was rejected for the square shape but retained for the loaf shape.

Thirdly, it was hypothesized that food cooked in a square or loaf container would have significantly higher temperatures in the corners than the round and tube containers would have at temperature points along the perimeter. The temperatures of the gelatin and custard in the loaf containers were significantly higher than the temperatures in the tube and round shapes. On the other hand, the temperatures of the square containers were not significantly different from the round and tube shapes.

Therefore, the hypothesis was rejected for the square shape and retained for the loaf shape. Thus one could expect that the corner temperatures of loaf containers would be higher than the temperatures that round and tube containers would have along the perimeter.

MATERIAL

Gelatin

In general, lower temperatures were obtained with clear glass and amber glass than with thermoset polyester and polysulfone, and glass materials differed significantly from plastic materials (Table 5). The clear glass and amber glass materials had similar temperatures which were significantly different from the thermoset polyester and polysulfone. For the four perimeter temperatures (A-D), the plastic materials, thermoset polyester and polysulfone, had significantly higher temperatures than the clear and amber glass materials. The other temperature results did not differ significantly among the four materials.

Temperatures were significantly different for all materials at location A (UL). At location B (UR), temperatures of materials were significantly different for clear glass and amber glass and thermoset polyester and polysulfone. This same trend was found for the temperature readings at C (LL) and D (LR).

Meltdown was significantly different for the four materials (Table 5). The clear glass and amber glass

TABLE 5

Means for Three Replications of Gelatin Temperatures and Meltdown by Container Material

	C Glass	A Glass	ThmSP	Poly
Temperature (C)				
A (UL)	29.17^{b}	30.22^{ab}	30.89^{a}	30.45^{a}
B (UR)	28.33^{b}	29.22^{b}	31.79^{a}	31.45^{a}
C (LL)	28.45^{b}	29.89^{a}	30.45^{a}	31.00^{a}
D (LR)	29.67^{b}	29.78^{b}	32.22^{a}	31.89^{a}
E[1] (C)	19.25^{b}	18.25^{b}	20.00^{a}	21.33^{a}
F[2] (IB)	25.00^{a}	---	24.67^{a}	23.33^{a}
G[2] (IR)	27.00^{a}	---	30.00^{a}	28.33^{a}
H[2] (IF)	23.00^{a}	---	25.00^{a}	26.33^{a}
Meltdown(ml)	185.00^{b}	175.00^{b}	221.11^{a}	232.22^{a}

[a,b] Means with different letters (a,b) in the same horizontal row are significantly different ($p < 0.05$) using the Duncan multiple range test.

[1] For the tube shape, E was located at the inside left while for the other shapes E was at the geometric center.

[2] Amber glass tube shape was not available, therefore no readings at F, G, and H.

materials had less melted gelatin than the thermoset polyester and polysulfone. These two generic materials, glass and plastic, were significantly different from each other. The clear glass had 185 ml of melted gelatin while the amber glass had 175 ml. The thermoset polyester and polysulfone materials had significantly more liquid, 221.11 ml and 232.22 ml, respectively, indicating that the gelatin had absorbed more microwave energy.

In summary, container material did make a significant difference in the temperatures and meltdown of gelatin. The two glass materials had significantly lower perimeter temperatures and meltdown (melted gelatin) than the thermoset polyester and polysulfone. In addition, the gelatin heated more evenly in the two plastic materials, thermoset polyester and polysulfone, as shown by a smaller variation in temperature readings among points A-D.

Custard

In general, temperature results for the four materials were significantly different from each other in tests with custard (Table 6). At points C (LL) and D (LR) temperature results were not significantly different.

At A (UL), amber glass was significantly different from the other materials. The temperature for the amber glass was 56.89 °C, while for the other three materials temperatures ranged from 70.25 °C to 75.56 °C. The temperature of the clear glass and thermoset polyester significantly differed

TABLE 6

Means for Three Replications of Custard Temperatures, Firmness, and Separation/Uncooked Portions by Container Material

	C Glass	A Glass	ThmSP	Poly
Temperature (C)				
A (UL)	70.25^{a}	56.89^{b}	75.56^{a}	71.11^{a}
B (UR)	71.58^{b}	72.33^{ab}	75.67^{a}	73.67^{ab}
C (LL)	72.75^{a}	69.89^{a}	71.11^{a}	71.11^{a}
D (LR)	72.42^{a}	71.56^{a}	71.56^{a}	73.78^{a}
E[1] (C)	67.83^{b}	64.00^{c}	69.79^{ab}	73.22^{a}
F[2] (IB)	81.67^{a}	---	70.33^{a}	72.33^{a}
G[2] (IR)	81.33^{a}	---	72.67^{a}	78.33^{a}
H[2] (IF)	79.00^{a}	---	69.33^{a}	74.00^{a}
Firmness (mm) in compression				
A (UL)	35.25^{a}	26.11^{a}	28.00^{a}	34.22^{a}
B (UR)	31.25^{a}	28.56^{a}	25.22^{a}	26.56^{a}
C (LL)	32.25^{a}	29.56^{a}	32.11^{a}	30.22^{a}
D (LR)	36.50^{a}	28.33^{a}	29.22^{a}	36.33^{a}
E[1] (C)	103.00^{a}	107.44^{a}	76.44^{a}	55.44^{a}
F[2] (IB)	42.67^{a}		40.00^{a}	38.00^{a}
G[2] (IR)	48.67^{a}	---	27.33^{ab}	19.33^{b}
H[2] (I	64.00^{a}	---	60.67^{a}	59.67^{a}
Separation/ Uncooked (ml)	19.00^{a}[3]	21.44^{a}[3]	19.89^{a}[3]	7.11^{b}[3]

[a,b,c] Means with different letters (a,b,c) in the same horizontal row are significantly different ($p < 0.05$) using the Duncan multiple range test.

[1] For the tube shape, E was located at the inside left while for the other shapes was at the geometric center.

[2] Amber glass tube shape was not available, therefore no readings at F, G, and H.

[3] Liquid resulting from uncooked portions and syneresis.

from each other but not with the other materials at B (UR). Significant results were determined between the glass and plastic materials at C (LL) and D (LR).

The two plastic materials had higher temperatures than the two glass materials. Clear glass containers had significantly higher temperatures at F (IB), G (IR), and H (IF) than the thermoset polyester and polysulfone at these locations.

Among the four materials, firmness was significantly different only at E (Table 6). The clear glass and amber glass materials had higher readings at that point, indicating a less firm product than in the thermoset polyester and polysulfone. The firmness measurement indicated a significantly firmer product in the thermoset polyester containers than in the containers of the other three materials.

The containers made of polysulfone had significantly less separation and uncooked custard than the glass and thermoset polyester containers (Table 6). The 7.11 ml of measured liquid from custard prepared in the polysulfone container was 62% less than from that prepared in the clear glass or the thermoset polyester and 69% less than in the amber glass.

The amount of separation or uncooked custard was not significantly different for containers of glass or thermoset polyester. Container material made more of a difference in the end temperature of the custard than in the firmness and separation or volume of uncooked portions.

Yellow Cakes

The height of yellow cakes was measured in centimeters at points (A-H) to determine an index to volume. Based on the means derived from the three replications, the height of the four materials was different for A-F (Table 7). No differences were found for points G (IR) and H (IF).

At A (UL), height of cakes prepared in the thermoset polyester containers was found to differ significantly from polysulfone but not from the clear glass and amber glass. The clear glass tended to have significantly less height at B (UR) than the amber glass. Both the clear glass and amber glass had significantly less height at C (LL) than did the thermoset polyester and polysulfone. Significant results for height at D (LR) indicate a lower height than the other materials.

The height for E was significantly different for amber glass and polysulfone. The height of the amber glass was lower than the other materials, while the polysulfone had the greatest height. No significant differences were found between the different materials of tube shapes.

The thermoset polyester differed significantly from the clear glass and polysulfone materials at location F (IB). Because amber glass containers did not include a tube shape, no height measurements are recorded for location F (IB), G

TABLE 7

Means for Three Replications of Height and Moisture Content in Cakes by Container Material

	C Glass	A Glass	ThmSP	Poly
Height (cm)				
A (UL)	4.65^{b}	4.70^{ab}	4.56^{b}	4.95^{a}
B (UR)	4.91^{b}	5.32^{a}	5.17^{ab}	5.04^{ab}
C (LL)	4.85^{b}	5.02^{b}	5.29^{a}	5.30^{a}
D (LR)	5.45^{a}	5.50^{a}	5.22^{a}	5.49^{a}
E[1] (C)	5.70^{b}	5.37^{c}	5.77^{ab}	6.04^{a}
F[2] (IB)	5.46^{a}	--	4.55^{b}	5.46^{a}
G[2] (IR)	5.92^{a}	--	4.97^{b}	5.37^{ab}
H[2] (IF)	5.69^{a}	--	5.41^{a}	5.65^{a}
Moisture Content (%)				
A (UL)	26.80^{a}	26.10^{a}	27.08^{a}	26.64^{a}
B (UR)	27.91^{a}	27.23^{ab}	27.21^{ab}	25.70^{a}
C (LL)	26.33^{a}	26.26^{a}	27.27^{a}	26.54^{a}
D (LR)	24.10^{a}	25.53^{a}	25.40^{a}	26.20^{a}
E[1] (C)	29.03^{a}	27.01^{a}	28.95^{a}	27.66^{a}
F[2] (IB)	22.50^{a}	---	25.73^{a}	24.57^{a}
G[2] (IR)	26.70^{a}	---	27.27^{a}	27.03^{a}
H[2] (IF)	28.53^{a}	---	29.40^{a}	28.37^{a}

[a,b,c] Means with different letters (a,b,c) in the same horizontal row are significantly different ($p < 0.05$) using the Duncan multiple range test.

[1] For the tube shape, E was located at the inside left while for the other shapes E was at the geometric center.

[2] Amber glass tube shape was not available, therefore no readings at F, G, and H.

(IR), and H (IF). These locations were found only on tube shaped containers.

No significant difference was determined for the moisture content of yellow cakes in the four materials (Table 7).

In summary, the height of yellow cakes was affected by container material while moisture content was not.

Hypothesis Related to Material

There was one hypothesis related to the container material. For the hypothesis that food prepared in amber glass containers will be more unevenly cooked (lower temperature, less melting, more uncooked portion) than in the other three containers, differences were found in the gelatin. Temperatures were lower and less melting occurred in the amber glass than in the thermoset polyester and polysulfone. For some temperature points, significant differences were found between clear glass and amber glass. With the custard,the amber glass had less firmness at E and more uncooked custard, both an indication of uneven heating, than the other materials. Although the temperature at E was lower in containers of amber glass than in containers of the other materials, this difference was not significant. Because the amber glass did heat the food more unevenly, the hypothesis is retained.

Interaction of Geometry and Material

Using ANOVA, the interaction of geometry and material on the food quality variables was studied for each food item (Table 8). These interactions show that the material did interact with shape and affected the food variables individually.

For the gelatin tests, the interaction of container geometry and material was determined for temperature measurements at points C (LL) and F (IB). Significant interactions were found at C (LL) and E. These interactions show that material and shape interacted with each other to determine the temperature at these points.

Geometry and material interacted to affect the temperatures of the custard at points A-E (Figure 8). At A (UL) and B (UR), shape and material were significant and the interaction was greater in the square amber glass container than any other. The square amber glass container had a significantly lower mean than the other shapes of the same materials. The influence of shape on the temperatures at points C (LL), D (LR), and E significantly depends on the material.

The firmness of custard is influenced by the interaction of shape and material only at E . Material interacted with shape significantly to determine the amount of separation liquid or uncooked custard that was measured in each container. The square containers of clear glass and amber glass had the most uncooked custard.

Only height of yellow cakes measured at points A-E was

TABLE 8

MEANS[1] FOR THREE REPLICATIONS FOR MEASURED VARIABLES BY CONTAINER GEOMETRY AND MATERIAL

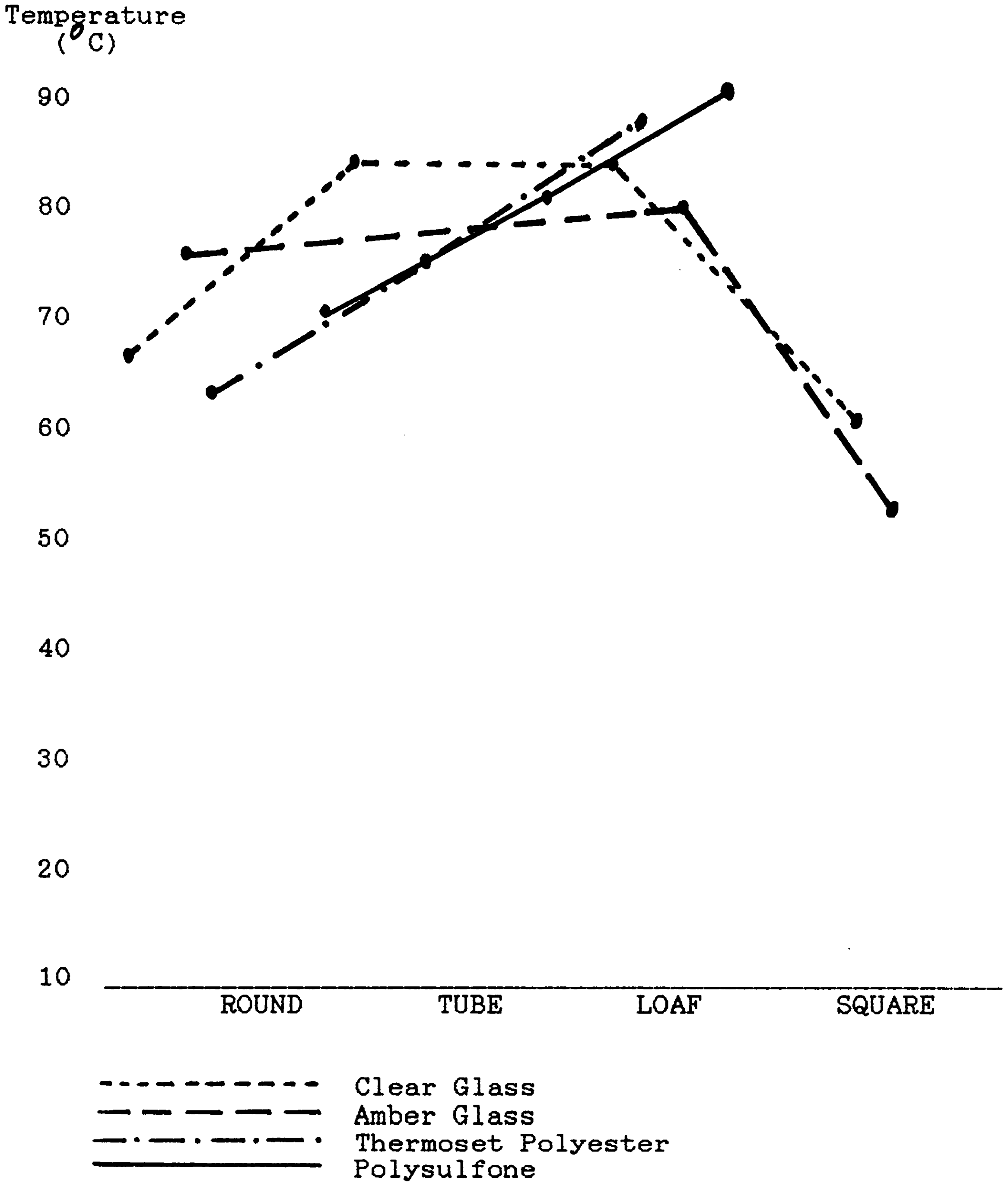
	ROUND	TUBE	LOAF	SQUARE
GELATIN				
Temp (°C)				
Clear glass	26.33	26.08	27.93	26.87
Amber glass	27.53	---	28.13	26.94
Thermst poly	28.80	28.09	29.40	---
Polysulfone	27.93	28.71	29.40	---
Meltdown (ml)				
Clear glass	221.67	173.33	171.67	173.33
Amber glass	188.33	---	175.00	161.67
Thermst poly	225.00	201.67	236.67	---
Polysulfone	236.67	231.67	228.33	---
CUSTARD				
Temp[2] (°C)				
Clear glass	64.73	80.38	80.20	58.73
Amber glass	71.06	---	78.20	51.53
Thermst poly	62.27	71.29	83.13	---
Polysulfone	64.00	72.92	82.00	---
Firmness (mm)				
Clear glass	48.20	48.75	43.60	51.87
Amber glass	43.73	---	42.13	46.13
Thermst poly	48.20	37.87	36.47	---
Polysulfone	36.73	37.75	39.93	---
Separation/ Uncooked (ml)				
Clear glass	18.33	3.00	6.33	48.33
Amber glass	9.33	---	4.33	50.67
Thermst poly	36.00	5.00	9.66	---
Polysulfone	7.00	5.00	9.33	---
CAKE				
Height[2] (cm)				
Clear glass	4.94	5.73	6.62	3.59
Amber glass	5.42	---	6.63	3.50
Thermst poly	4.23	4.94	6.45	---
Polysulfone	4.49	5.20	6.58	---
Moisture Cnt (%)				
Clear glass	27.85	26.28	25.91	27.09
Amber glass	28.40	---	26.08	27.22
Thermst poly	27.97	27.25	26.46	---
Polysulfone	28.08	26.63	24.96	---

[1] No means are included for tube amber glass, square thermoset polyester, and square polysulfone containers because these containers were not available for testing.

[2] Indicates a significant interaction of geometry and material.

FIGURE 8

INTERACTION OF SHAPE AND MATERIAL
CUSTARD TEMPERATURES



found to be significantly affected by the interaction of shape and material which did determine if a cake would have a high or low volume (Figure 9). No interactions were determined for moisture content of cakes.

In summary, shape and material interacted with each other to determine the temperature of gelatin and firmness of custard at point E. Also, this interaction influenced custard temperature temperatures (A-E), custard separation, uncooked custard, and cake volume (A-E). Therefore, material and shape did interact with each other to affect the quality of the foods tested.

Summary of the Results

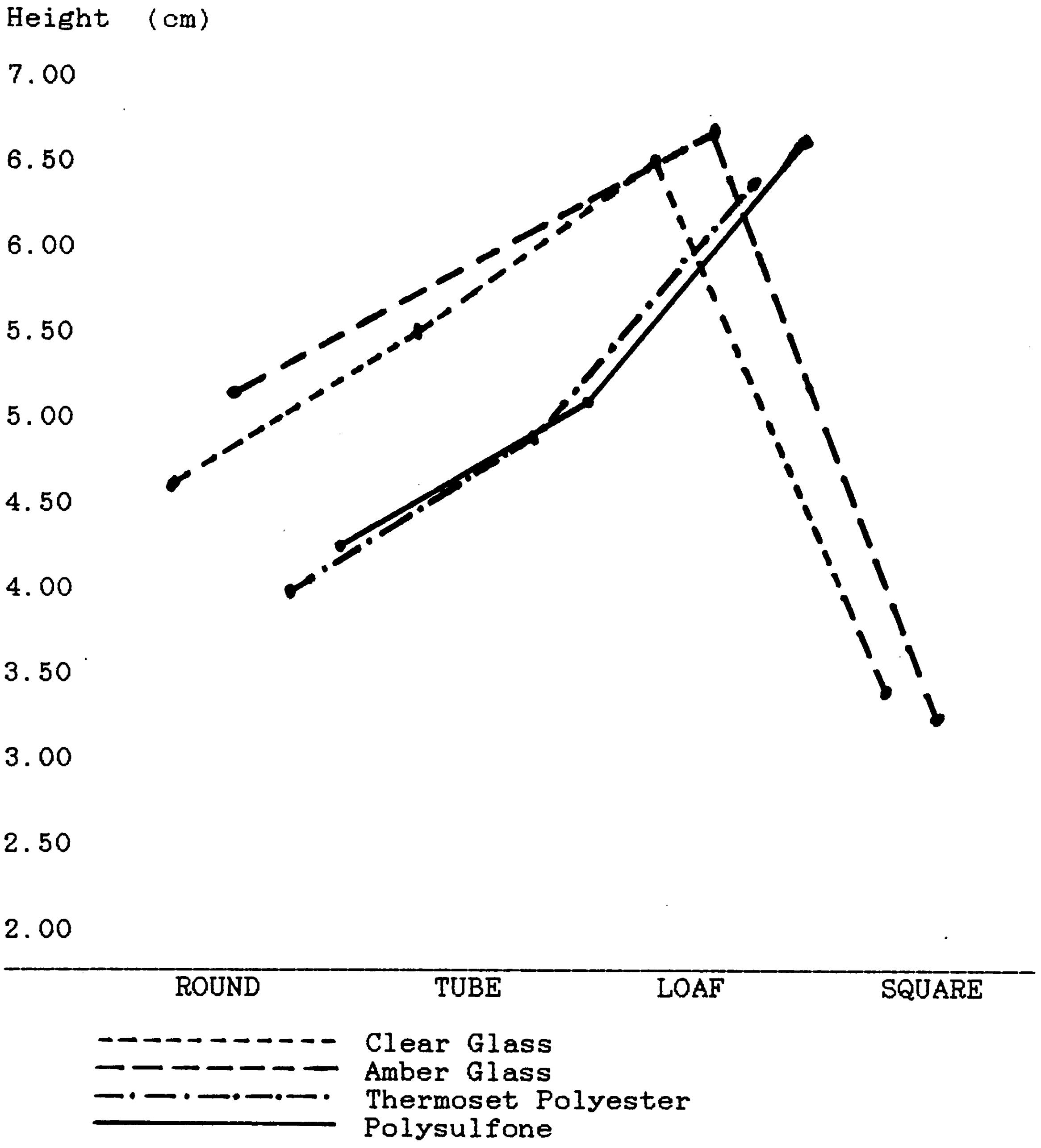
Based on the results of this study, the following generalizations can be made:

- The shape of the container does affect the quality of food prepared in the microwave appliance. For some food items (gelatin and custard temperatures), round and tube shapes produced significantly different results from other shapes, while in other foods (custard firmness, moisture content)this was not found. Results with shapes were inconsistent except for square shapes in which uneven cooking was observed.

- The material of the container did affect the cooking performance but no one material was consistently different for all foods. Differences were found between generic groupings of materials, with the glass containers differing

FIGURE 9

INTERACTION OF SHAPE AND MATERIAL
CAKE HEIGHT



significantly from the plastics.

- Shape and material did interact with each other for some food variables. Specifically, these were custard temperatures , cake volume, and custard separation/uncooked portions.

Discussion

In this study, significant differences were found between shapes for some food variables but not for others. Custard and gelatin heated more evenly in the round and tube containers than in the square but no significant differences were found when round and tube shapes were compared with the loaf. The contents of square containers were unevenly heated as there was more uncooked custard and more temperature differences than with the other shapes. This result substantiates the work of Van Zante (1963) who found that agar heated more evenly in round pans than in square containers.

Writers in Consumer Reports ("Microwave Cookware, 1981) and Van Zante (1963) reported that food heated in square and rectangular containers overcooked in the corners, an indication of high temperatures. The results of this study did show significantly higher temperatures only in certain corners of square and rectangular (loaf) containers. The several factors which could have caused a difference in the results of this study compared to previous research are: heating times, quantity of food load, type of food load, output wattage of the microwave appliance, and pattern of microwave distribution system within the cavity.

The custard heated in the tube shape had no uncooked portions, an indication of an evenly cooked product. The temperature readings for the gelatin and custard in the tube shape differed significantly from temperatures for those foods prepared in the other shapes. However, no significant differences was found for the moisture content of the yellow cake prepared in the tube shape compared to cakes heated in the round, loaf, and square containers. These findings do not substantiate the recommendation made by Colato (1978) that the tube or donut shape is the most efficient shape. The reasons that the tube shape was not found to be the most efficient for all food loads may be explained by the facts that microwave appliances today have a better distribution system and containers are designed with the microwave appliance in mind. Also, the square and loaf containers used in this study did not have 90 degree angles at the corners. The corners were rounded, allowing for a more uniform heating.

Sando et al (1984) found that, when heated in glass bottles, the temperature of baby formula was higher than when heated in plastic bottles. The results of this study do not substantiate that report. Custard and gelatin temperatures were found to be significantly higher in the two plastic containers, thermoset polyester and polysulfone, than in the clear glass and amber glass containers. This difference in results may be due to the formulation of the container materials, quantity of food load, placement of food load in the appliance cavity, or the dimensions and characteristics of surface areas of the containers.

Writers in *Consumer Reports* ("Microwave Cookware,"1981) reported that container materials of glass, ceramic, and plastic had no discernible effect on how food cooked in a microwave appliance. The results of this study show that the plastics, thermoset polyester and polysulfone, performed significantly different from the other materials for temperatures and separation of the custard. These differences may be due to food load, heating times, or specific types of materials used.

A comparison of clear glass and amber glass resulted in the finding that amber glass was not significantly different (α.05) from the clear glass except for temperatures at A (UL) and E (C) and firmness at point A (UL) for custard and at temperature points A (UL) and C (LL) for gelatin. The custard heated in the amber glass had a lower center temperature than the other materials, an indication of uneven cooking. The square amber container had a unique occurrance at point A (upper right-hand corner of the container) when custard was prepared in it. Near the completion of the cooking, the custard at this area had a large air bubble that burst and forced the custard away from the corner, therefore no temperature readings could be taken. This occurred for two replications. The volume reading for the yellow cake at this point was significantly lower than in the other containers: the cake had a large indentation at this point.

Results of this study indicate that the shape affects cooking performance more than does material. Significant differences occurred more often between container geometry than container material. Shape influenced performance more because the shape of the container determines the angle in which microwaves penetrate the container. In square or loaf shapes, more energy penetrates the container in the corners which may cause food to overcook in these locations. In a circular shape, the microwaves enter the container from one side thus more even heating occurs. Also, the exposed surface area differs with the shape of the container. An eight inch square container has a perimeter of 32 inches, while the eight and nine inch round containers have perimeters of 25.1 inches and 28.3 inches respectively. The amount of surface area that is exposed affects cooking performance. The more exposed surface area, the faster the food will cook, assuming the depth of the food load is the same.

The container material does not affect the microwave performance as does shape because materials used in this study all allowed microwaves to pass through the containers. When food is heated in the microwave appliance, the material selected should be one that permits microwaves to pass through the container to heat the food.

Color or opacity has been thought to have an effect on microwave performance. Van Zante (1961) found that agar heated more rapidly in a microwave glass container than in a dark earthenware container. If the amber glass and opaque plastics could be considered dark containers, the results of this study do not substantiate the statement of Van Zante (1961) that dark containers heat food more unevenly than a clear container. However, the findings in the Van Zante (1961) study may have resulted from a difference in material, earthenware versus glass, rather than a difference in color between containers.

CHAPTER V

SUMMARY AND RECOMMENDATIONS

Summary

As the domestic use of microwave appliances has increased dramatically over the past decade, so has the growth of the microwave cookware market. Today's consumers are offered an array of microwave containers in many shapes and sizes made of a variety of materials. Consumers need to know which shapes and materials of microwave cookware perform best in the microwave appliance. There has been limited independent research published on the comparison of microwave cookware shape and material as it affects food quality. Thus, this research was designed to provide information about differences in rate of cooking in round, tube, loaf, and square containers of glass or plastic.

The data for this study were collected in the Virginia Polytechnic Institute and State University household equipment laboratory during the spring of 1986. In three replications, three food items were heated in a microwave appliance using round, tube, loaf, and square containers made of clear glass, amber glass, thermoset polyester, and polysulfone. Cooking times, power levels, and recipes were those suggested in manufacturers' recipes, use and care guides for microwave appliances, and instructions from packages.

Performance as indicated by food quality was determined by comparing temperature, meltdown, firmness, separation/uncooked portions, volume, and moisture content. Procedures used in the statistical analysis of the data included ANOVA, Duncan's multiple range test, means, standard deviations, and ranges.

Conclusions

Based on the results of these tests, the major conclusions were that:

- Performance of the microwave appliance as indicated by food quality was affected more by the shape of the container than by material.

- More even cooking results were found with the tube and round shape containers than with the square shape. At the center of the containers, the square shape had lower temperatures and less firmness. Fewer differences were found between the loaf shape and the tube shape.

- Foods prepared in the plastic containers were more evenly heated than in the glass containers.

- The interaction of shape and material was greater as the heating time increased. Interaction occurred between shape and material for cake height and custard temperatures. Little or no interaction was found for custard firmness, moisture content, and gelatin temperatures.

Implications

Major findings of this study suggest that the type of microwave cookware chosen can make a difference in the quality of food produced. Users of microwave appliances can choose a container that will give optimum results if they remember that, in general, the shape of a container affects food quality more than material.

When preparing to heat food in a microwave appliance, consumers should first choose a container by its shape, then by its material. Some foods cook more evenly in a tube shape, and while round shapes produced satisfactory results, the loaf containers tested in this study resulted in significant differences when compared with the round shape. Because cooking is uneven in a square shape, regardless of the material, consumers should avoid this shape container.

Consumers do not need many different shapes and materials of microwave cookware to achieve good cooking results from their appliance. They may want to have a variety of sizes to meet all their cooking needs, but regardless of size (volume) they should select containers that are round or tube shaped in a material that transmits microwaves.

Limitations and Recommendations

The following recommendations for further study have been derived from the limitations of this study:

Limitation. One microwave appliance (Whirlpool, Model MW8750XP) was used in this study.

Recommendation Further research is needed to determine if these findings hold true for other brands and models of microwave appliances. Models are different because of the output wattages (440-700 watts), size of the cavity (large countertop versus under-the-cabinet models), and microwave distribution pattern used (microwaves entering the cavity from the top only, from the top and bottom, from a rotating device, or from all four sides).

Limitation The number of food items tested in this study was limited.

Recommendation Further research is necessary using other foods that do require stirring or turning to determine whether these results hold true for these foods.

Recommendation Further research is needed to determine whether the findings are generalizable to other foods with similar or other characteristics.

Limitation Only four shapes of cookware made of four materials were studied.

Recommendation Further research is needed to determine results when using microwave cookware in other combinations of shapes and materials.

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APPENDIX A

SPECIFIC PROCEDURES

Unflavored Gelatin

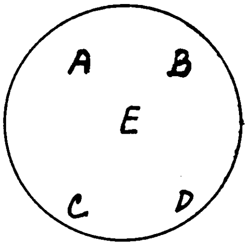
Preparation - amount each test container.

In a large glass bowl, soften 1 envelope unflavored gelatin in 59mL (1/4 c) cold 20°C (68°F) water. Add 237mL (1 c) boiling water, stir until gelatin is dissolved. Add 177mL (3/4 c) cold 20°C water. Let stand for 5.00 minutes. Pour into test container. Cover with plastic wrap and refrigerate for 24 hours. Remove from refrigerator. Remove cover.

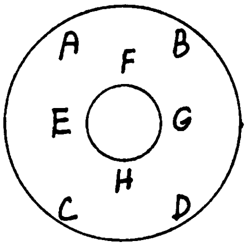
Place gelatin in microwave appliance in center of shelf bottom. Set appliance controls for full (100%) power, 1.00 minute. Start stopwatch and microwave appliance simultaneously. Heat for 1.00 minute. Remove gelatin from the microwave and place on a counter. Record visual observations. Let stand for 1.00 minute. Proceed with testing for food quality variables.

Tests for Food Quality Variables

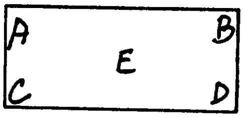
Temperature- After 1 minute standing time, measure temperatures at points A-H, mid-depth of the gelatin. All 5 or 8 (for the tube dish) temperature points are measured at the same time using a template with holes for 5 or 8 thermometers which are placed in the template so that the thermometer point is mid-depth of the gelatin.



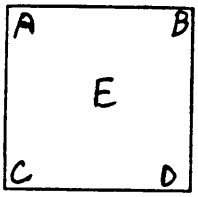
ROUND



TUBE



LOAF



SQUARE

Meltdown - Plug glass funnel hole with wad of glass wool large enough to cover the hole. Place funnel end inside a graduated cylinder. Pour heated gelatin into funnel. Drain for 1 minute. Measure liquid in graduated cylinder. Record.

Baked Custard

<u>Preparation</u>- amount for each test container.

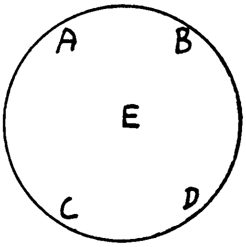
In a 1 liter (4 c) liquid measure, place 473mL (2 c) 5° C (40 °F) milk. Cook on high (100% power level) for 4.00 minutes; milk should be hot but not boiling. In a large mixing bowl beat 177g eggs (4 medium) with an electric mixer using speed 1, lowest speed, for 1.00 minute. Add 58g (1/3 c) sugar, 5mL (1 tsp) vanilla and a dash of salt. Mix together for .25 minutes using speed 1, lowest speed. Gradually add hot milk to egg mixture and mix for .50 minutes using speed 1. Stop mixer. Pour into baking dish. Record temperature of uncooked custard.

Place custard in microwave appliance in center of bottom shelf. Set appliance controls on 50% power, 11:00 minutes.

Start stopwatch and microwave simultaneously. Heat for 11:00 minutes. Stop appliance. Remove custard from the microwave appliance and place on a counter. Record visual observations. Let stand for five minutes and proceed with variable testing.

Tests for Food Quality Variables

Temperature- After five minutes standing time, measure temperatures at A-H, mid-depth of the custard. All 5 or 8 (for tube dish) temperatures are measured at the same time using a template with holes for placement of 5 or 8 thermometers which are placed in the template so that the thermometer point is mid-depth of the baked custard.



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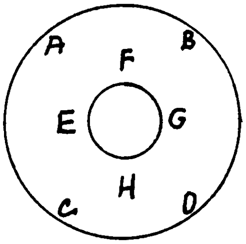
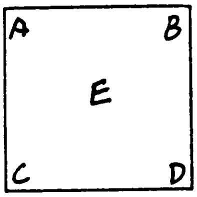


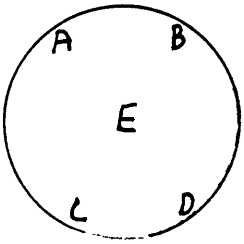
TUBE

LOAF



SQUARE

Firmness. Using a penetrometer, measure firmness at points A-H. Record.



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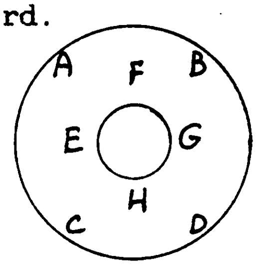
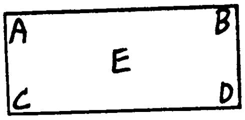


TUBE



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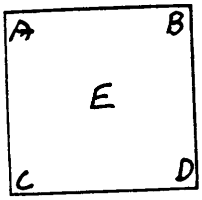


SQUARE

Separation/uncooked portion- Pour custard into National Bureau of Standards sieve of 9 meshes/inch with catch pan. Drain for 2 minutes. Pour drained liquid into graduated cylinder. Record volume.

Yellow Layer Cake

Preparation

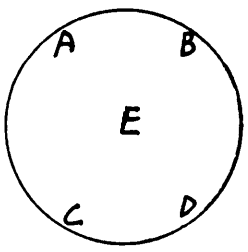
In a small mixing bowl, place 275 g (9 1/4 oz) dry yellow cake mix, 79mL (1/3 c) oil, 67 g (1 1/2 medium) eggs and 118 mL (5/8 c) 22°C (72°F) water. Mix together with an electric mixer using speed 1, lowest speed, for .50 minutes, then speed 6, medium speed, for 2.50 minutes. Pour batter into prepared microwave baking dish, greased and lined with wax paper.

Place cake in the center of bottom shelf of the microwave appliance. Set appliance on 70% power for 8:00 minutes. Start stopwatch and microwave simultaneously. Heat for 8:00 minutes. Stop appliance. Remove cake from the microwave; set on counter. Record visual observations.

Cool cake for 10 minutes, turn out of dish and proceed with variable testing.

Tests for Food Quality Variables

Index to volume- Using a vernier caliper, measure height at points A-H.



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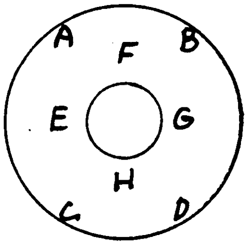

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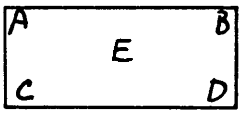

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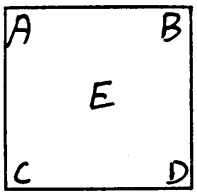
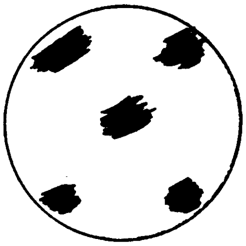


SQUARE

Moisture content - Using a corer, cut samples from the shaded areas. Finely chop each sample, measure 10 g, and place in moisture/volatile tester for 60 minutes or until weight becomes constant. The center of each shaded area is the point where height was measured.



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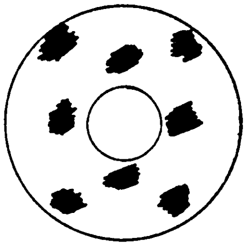

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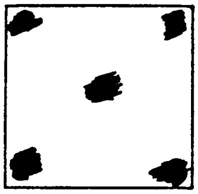

SQUARE

APPENDIX B

DATA COLLECTION SHEETS

ID #____________

DATA COLLECTION SHEET

Food item: Gelatin

Cookware

Shape_________________

Material______________

	Test 1	Test 2	Test 3	Mean
Test #	______	_______	_______	
Date	______	_______	_______	
Environmental Conditions				
Temperature	______	_______	_______	______
Humidity	______	_______	_______	______
Atmospheric Pressure	______	_______	_______	______
Power Level	______	_______	_______	

Visual Observations

ID #__________

	Test 1	Test 2	Test 3	Mean
Temperature				
A				
B				
C				
D				
E				
F				
G				
H				
Meltdown				

ID #__________

DATA COLLECTION SHEET

Food item: Baked custard

Cookware

Shape ____________________

Material ____________________

	Test 1	Test 2	Test 3	Mean
Test #	______	______	______	
Date	______	______	______	
Environmental Conditions				
Temperature	______	______	______	______
Humidity	______	______	______	______
Atmospheric Pressure	______	______	______	______
Power Level	______	______	______	
Temperature before Heating	______	______	______	______

Visual Observations

ID #__________

	Test 1	Test 2	Test 3	Mean
Temperature				
A	______	______	______	______
B	______	______	______	______
C	______	______	______	______
D	______	______	______	______
E	______	______	______	______
F	______	______	______	______
G	______	______	______	______
H	______	______	______	______
Firmness				
A	______	______	______	______
B	______	______	______	______
C	______	______	______	______
D	______	______	______	______
E	______	______	______	______
F	______	______	______	______
G	______	______	______	______
H	______	______	______	______
Separation/ Uncooked Amount	______	______	______	______

ID#____________________

DATA COLLECTION SHEET

Food item: Yellow layer cake

Cookware

Shape____________________

Material__________________

	Test 1	Test 2	Test 3	Mean
Test #	______	_______	_______	
Date	______	_______	_______	
Environmental Conditions				
Temperature	______	_______	_______	______
Humidity	______	_______	_______	______
Atmospheric Pressure	______	_______	_______	______
Power Level	______	_______	_______	

Visual Observations

ID #__________

	Test 1	Test 2	Test 3	Mean
Index to Volume (Height)				
A	______	______	______	______
B	______	______	______	______
C	______	______	______	______
D	______	______	______	______
E	______	______	______	______
F	______	______	______	______
G	______	______	______	______
H	______	______	______	______
Moisture Content				
A	______	______	______	______
B	______	______	______	______
C	______	______	______	______
D	______	______	______	______
E	______	______	______	______
F	______	______	______	______
G	______	______	______	______
H	______	______	______	______

APPENDIX C

SPECIFIC RESULTS

TABLE 9

Gelatin Tests; Results by Variables, Container Geometry and Material

ROUND SHAPE

	Temperature °C								Meltdown (ml)
	A	B	C	D	E	F	G	H	
CLEAR GLASS									
Mean	28.00	28.67	29.33	30.00	15.67	---	---	---	221.67
Std. Dev	1.00	2.31	1.15	0	1.15	---	---	---	20.82
Range	27-29	26-30	28-30	30-30	15-17	---	---	---	205-245
AMBER GLASS									
Mean	29.33	29.00	30.33	29.33	19.67	---	---	---	188.33
Std. Dev	1.53	1.00	1.15	1.15	1.53	---	---	---	10.41
Range	28-31	28-30	29-31	28-30	18-21	---	---	---	180-200
THRMST POLY									
Mean	30.33	30.67	31.33	31.33	20.33	---	---	---	225.00
Std. Dev	.58	1.15	.58	1.15	.58	---	---	---	30.00
Range	30-31	30-32	31-32	30-32	20-21	---	---	---	195-255
POLYSULFONE									
Mean	28.33	30.33	29.67	31.00	20.33	---	---	---	236.67
Std. Dev	.58	.58	.58	1.00	.58	---	---	---	7.64
Range	28-29	30-31	29-30	30-32	20-21				230-245

Ne data are included for F, G, and H; round shape did not have these points.

TABLE 10

Gelatin Tests; Results by Variables, Container Geometry and Material

TUBE SHAPE

	Temperature °C								Meltdown (ml)
	A	B	C	D	E	F	G	H	
CLEAR GLASS									
Mean	28.33	26.00	25.67	28.67	25.00	25.00	27.00	23.00	173.33
Std. Dev	.58	3.46	1.15	1.53	1.00	3.46	2.00	4.36	58.85
Range	28-29	24-30	25-27	27-30	24-26	23-29	25-29	20-28	130-235
AMBER GLASS									
THRMST POLY									
Mean	30.67	30.67	27.67	31.67	24.33	24.67	30.00	25.00	201.67
Std. Dev	.58	3.46	1.15	1.53	1.00	3.46	2.00	4.36	15.28
Range	28-29	24-30	25-27	27-30	24-26	25-29	25-29	20-28	185-215
POLYSULFONE									
Mean	31.67	31.67	31.33	31.67	25.33	25.33	28.33	26.33	232.67
Std. Dev	2.08	1.15	1.58	1.15	2.31	3.06	1.53	.58	35.53
Range	30-34	31-33	30-33	31-33	24-28	20-26	27-30	26-27	210-275

No data are included for amber glass because this container was not available for testing.

TABLE 11

Gelatin Tests: Results by Variables, Container Geometry and Material

LOAF SHAPE

	Temperature °C								Meltdown (ml)
	A	B	C	D	E	F	G	H	
CLEAR GLASS									
Mean	31.33	31.33	29.67	31.00	16.33	---	---	---	171.67
Std. Dev	.58	1.15	.58	1.00	2.52	---	---	---	2.89
Range	31-32	30-32	29-30	30-32	14-19	---	---	---	170-175
AMBER GLASS									
Mean	31.67	31.00	29.67	31.00	17.33	---	---	---	175.00
Std. Dev	1.53	0	.58	1.00	2.52	---	---	---	5.00
Range	30-33	31-31	29-30	30-32	15-20	---	---	---	170-180
THRMST POLY									
Mean	31.67	34.00	32.33	33.67	15.33	---	---	---	236.67
Std. Dev	2.08	1.00	1.15	1.53	.58	---	---	---	24.66
Range	30-34	33-35	31-33	32-35	15-16	---	---	---	220-265
POLYSULFONE									
Mean	31.11	32.33	32.00	33.00	18.33	---	---	---	228.33
Std. Dev	..58	.58	1.00	1.00	.58	---	---	---	17.56
Range	31-32	32-33	31-33	32-34	18-19	---	---	---	210-245

No data are included for F, G, and H; loaf shape did not have these points.

TABLE 12

Gelatin Tests: Results by Variables, Container Geometry and Material

SQUARE SHAPE

	Temperature °C								Meltdown (ml)
	A	B	C	D	E	F	G	H	
CLEAR GLASS									
Mean	29.00	27.33	29.00	29.00	20.00	---	---	---	173.33
Std. Dev	1.73	2.09	2.65	1.00	2.00	---	---	---	36.86
Range	27-30	25-29	26-31	28-30	18-22	---	---	---	145-215
AMBER GLASS									
Mean	29.67	27.67	29.67	29.00	18.67	---	---	---	161.67
Std. Dev	.58	2.08	2.89	1.00	1.53	---	---	---	15.28
Range	29-30	26-30	28-33	28-30	17-20	---	---	---	145-175

No data are included for F, G, and H; square shape did not have these points.

No data are included for thermoset polyester and polysulfone; these containers were not available for testing.

TABLE 13

Custard Tests: Results by Variables, Container Geometry and Material

ROUND SHAPE

	Temperatures °C								Firmness (mm)								Separation/Uncooked (ml)
	A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H	
CLEAR GLASS																	
Mean	63.00	64.67	68.33	69.33	58.33	---	---	---	38.33	31.67	35.67	32.33	103.33	---	---	---	18.33
Std..Dev	3.61	1.53	4.51	4.04	3.06	---	---	---	14.01	5.51	4.62	7.51	14.93	---	---	---	4.73
Range	60-67	63-66	64-73	65-73	55-61	---	---	---	24-52	26-37	33-41	25-40	92-120	---	---	---	13-22
AMBER GLASS																	
Mean	73.00	76.33	70.33	72.67	63.00	---	---	---	34.33	46.00	31.67	32.67	74.00	---	---	---	9.33
Std. Dev	2.65	3.79	3.06	1.53	4.58	---	---	---	.58	13.86	8.96	9.81	4.58	---	---	---	3.06
Range	70-75	72-79	67-73	71-74	59-68	---	---	---	34-35	38-62	26-42	27-44	70-79	---	---	---	6-12
THRMST POLY																	
Mean	63.67	66.67	62.33	62.00	56.67	---	---	---	33.67	22.67	31.33	38.33	115.00	---	---	---	36.0
Std. Dev	4.04	7.34	1.53	1.00	2.08	---	---	---	7.09	3.21	4.62	22.50	36.76	---	---	---	13.86
Range	60-68	61-75	61-64	61-63	55-59	---	---	---	26-40	19-25	26-34	16-61	85-156	---	---	---	20-44
POLYSULFONE																	
Mean	61.67	66.00	64.00	66.67	61.67	---	---	---	31.00	16.00	30.33	35.67	70.67	---	---	---	7.00
Std. Dev	3.79	1.73	2.00	4.16	1.53	---	---	---	6.24	5.57	5.69	6.43	2.31	---	---	---	2.00
Range	59-66	65-68	62-66	62-70	60-63	---	---	---	26-38	10-21	24-35	31-43	68-72	---	---	---	5-9

No data are included for F, G, and H; round shape did not have these points.

TABLE 14

Custard Tests: Results by Variables, Container Geometry and Material

TUBE SHAPE

	Temperature °C								Firmness (mm)								Separation/Uncooked (ml)
	A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H	
CLEAR GLASS																	
Mean	79.67	79.00	80.33	80.33	81.67	81.67	81.33	79.00	49.67	42.00	43.33	50.67	49.00	42.67	48.67	64.00	3.0
Std. Dev	4.51	5.29	4.73	4.93	.58	2.08	3.05	1.73	14.64	29.21	11.93	12.42	10.58	15.37	20.31	23.90	4.73
Range	75-84	75-85	75-84	77-86	81-82	80-84	78-84	78-81	34-63	11-69	35-57	43-65	37-57	25-53	35-72	43-90	2-4
AMBER GLASS																	
THRMST POLY																	
Mean	73.00	75.00	68.67	71.00	70.33	70.33	72.67	69.33	29.33	33.69	34.33	12.00	40.33	40.00	27.33	60.67	5.00
Std. Dev	2.00	3.46	1.15	1.73	4.51	6.51	2.08	2.08	15.95	9.07	8.74	9.54	2.08	8.89	2.52	8.08	2.65
Range	71-75	71-77	68-70	70-73	66-75	64-77	71-75	67-71	16-47	24-42	27-44	6-23	38-42	33-50	25-30	52-68	2-7
POLYSULFONE																	
Mean	71.67	73.67	67.33	71.67	74.33	72.33	78.33	74.00	39.67	35.67	41.00	28.67	40.00	38.00	19.33	59.67	5.00
Std. Dev	2.08	2.31	4.16	3.06	4.93	2.08	2.89	4.00	8.96	28.04	21.38	7.09	9.54	13.23	9.29	12.50	3.00
Range	70-74	71-75	64-72	69-75	71-80	70-74	75-80	70-78	34-50	16-68	24-65	21-35	31-50	28-53	13-30	47-72	2-8

No data are included for amber glass because this container was not available for testing.

TABLE 15

Custard Tests: Results by Variables, Container Geometry and Material

LOAF SHAPE

	Temperature °C								Firmness (mm)								Separation/Uncooked (ml)
	A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H	
CLEAR GLASS																	
Mean	80.00	83.67	81.00	79.00	77.33	---	---	---	34.00	27.67	31.67	44.33	80.33	---	---	---	6.33
Std. Dev	5.57	2.31	1.00	4.00	4.93	---	---	---	15.59	15.14	9.07	16.19	13.05	---	---	---	2.31
Range	74-85	81-85	80-82	75-83	74-83	---	---	---	25-52	17-45	25-42	34-63	70-95	---	---	---	4-8
AMBER GLASS														---	---	---	4.33
Mean	77.67	82.33	77.33	80.67	73.00	---	---	---	33.00	14.67	42.67	35.33	85.00	---	---	---	4.33
Std. Dev	4.04	2.52	3.21	1.15	7.21	---	---	---	27.78	3.51	15.95	17.03	13.23	---	---	---	2.31
Range	73-80	80-85	75-81	80-82	65-79	---	---	---	15-65	11-18	32-61	25-55	75-100	---	---	---	3-7
THRMST POLY																	
Mean	84.00	85.33	82.33	81.67	82.33	---	---	---	21.00	19.33	30.67	37.33	74.00	---	---	---	9.66
Std. Dev	1.00	.58	2.52	1.53	1.53	---	---	---	2.00	6.03	16.77	10.02	7.21	---	---	---	4.04
Range	83-85	85-86	80-85	80-83	81-84	---	---	---	19-23	13-25	20-50	27-47	68-82	---	---	---	5-12
POLYSULFONE																	
Mean	80.00	81.33	82.00	83.00	83.67	---	---	---	32.00	28.00	19.33	44.67	55.67	---	---	---	9.33
Std. Dev	0.00	1.15	1.73	1.00	1.53	---	---	---	6.08	9.54	9.02	8.50	6.03	---	---	---	3.06
Range	80-80	80-82	80-83	82-84	82-85	---	---	---	28-39	18-37	10-28	35-51	50-62	---	---	---	6-12

No data are included for F, G, and H; loaf shape did not have these points.

TABLE 16

Custard Tests: Results by Variables, Container Geometry and Material

SQUARE SHAPE

	Temperatures °C								Firmness (mm)								Separation/Uncooked (ml)
	A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H	
CLEAR GLASS																	
Mean	58.33	59.00	61.33	61.00	54.00	---	---	---	19.00	23.67	18.33	18.67	179.67	---	---	---	48.33
Std. Dev	4.93	4.00	1.53	2.00	2.65	---	---	---	6.24	8.50	9.50	9.03	7.64	---	---	---	15.28
Range	55-64	55-63	60-63	59-63	51-56	---	---	---	12-24	15-32	9-28	13-25	173-188	---	---	---	35-65
AMBER GLASS																	
Mean	20.00	58.33	62.00	61.33	56.00	---	---	---	11.00	25.00	14.33	17.00	163.33	---	---	---	50.67
Std. Dev	34.64	1.53	6.08	4.93	2.65	---	---	---	9.54	3.61	11.02	6.56	12.58	---	---	---	16.92
Range	0-60	57-60	58-69	58-67	54-59	---	---	---	0-17	21-28	7-27	10-23	150-175	---	---	---	32-65

No data are included for F, G, and H; square shape did not have these points.

No data are included for thermoset polyester and polysulfone; these containers were not available for testing.

TABLE 17

Yellow Cake Tests: Results by Variables, Container Geometry and Material

ROUND SHAPE

	Height (cm)								Moisture Content (%)							
	A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H
CLEAR GLASS																
Mean	4.01	3.82	4.50	4.86	5.28	---	---	---	28.17	28.53	27.80	23.93	30.80	---	---	---
Std. Dev	.13	.22	.19	.11	.01	---	---	---	1.50	2.14	1.48	1.72	1.49	---	---	---
Range	3.92-4.16	3.61-4.05	4.32-4.69	4.79-4.98	5.28-5.29	---	---	---	27.2-19.9	27.2-31.0	26.8-29.5	22.8-25.5	29.7-32.5	---	---	---
AMBER GLASS																
Mean	5.49	5.48	5.30	5.65	5.16	---	---	---	27.53	27.23	29.50	28.17	30.57	---	---	---
Std. Dev	.17	.41	.10	.50	.23	---	---	---	1.75	2.31	1.35	3.59	1.03	---	---	---
Range	5.32-5.66	5.24-5.96	5.24-5.41	5.18-5.42	5.02-5.42	---	---	---	25.6-29.0	24.6-28.9	27.0-29.6	24.2-31.2	29.7-31.7	---	---	---
THRMST POLY																
Mean	3.58	4.47	4.01	4.11	4.98	---	---	---	28.57	28.63	27.57	23.43	31.63	---	---	---
Std. Dev	.22	.04	.19	.16	.30	---	---	---	2.61	1.88	2.72	3.97	1.82	---	---	---
Range	3.40-3.83	4.43-4.50	3.82-4.19	4.00-4.29	4.75-5.32	---	---	---	26.5-31.2	27.4-30.8	25.9-30.7	20.8-28.0	30.0-33.6	---	---	---
POLYSULFONE																
Mean	3.99	3.98	4.23	4.61	5.63	---	---	---	28.00	27.60	27.93	29.33	27.53	---	---	---
Std. Dev	.73	.30	.30	.28	.50	---	---	---	1.64	1.49	.96	1.82	3.96	---	---	---
Range	3.23-4.68	3.78-4.32	3.98-4.56	4.32-4.88	5.16-6.15	---	---	---	26.2-29.4	25.9-28.7	26.9-28.8	27.3-30.8	23.4-31.3	---	---	---

No data are included for F, G and H; round shape did not have these points.

TABLE 18

Yellow Cake Tests: Results by Variables, Container Geometry and Material

TUBE SHAPE

	Height (cm)								Moisture Content (%)							
	A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H
CLEAR GLASS																
Mean	5.66	5.53	5.76	5.92	5.93	5.46	5.92	5.69	25.73	27.20	26.97	26.47	26.13	22.50	26.70	28.53
Std. Dev	.29	.29	.10	.19	.13	.31	.59	.41	1.94	1.93	2.01	1.94	2.11	.82	2.08	1.85
Range	5.33-5.89	5.20-5.75	5.65-5.85	5.77-6.14	5.85-6.08	5.11-5.68	5.30-6.47	5.25-6.07	23.6-27.4	25.8-29.4	25.1-29.1	25.2-28.7	23.9-28.1	21.6-23.2	25.4-29.1	26.4-29.7
AMBER GLASS																
THRMST POLY																
Mean	4.17	5.05	5.57	4.48	5.32	4.55	4.97	5.41	26.70	27.10	28.30	27.33	26.13	25.73	27.27	29.40
Std. Dev	.18	.04	.19	.23	.52	.32	.33	.10	2.26	2.20	1.22	3.10	.49	3.98	3.74	1.01
Range	4.00-4.35	5.00-5.08	5.35-5.69	4.21-4.62	4.72-5.67	4.20-4.82	4.60-5.25	5.35-5.52	24.6-29.1	24.9-29.3	26.9-29.1	24.3-30.5	25.8-26.7	23.0-30.3	23.9-31.3	28.5-30.5
POLYSULFONE																
Mean	4.27	4.73	5.30	5.49	5.35	5.46	5.37	5.65	27.00	24.37	26.90	25.90	28.87	24.57	27.03	28.37
Std. Dev	.12	.36	.07	.23	.23	.14	.18	.32	.66	.51	.85	.40	1.26	.97	3.27	1.21
Range	4.20-4.40	4.32-4.95	5.24-5.38	5.23-5.68	5.12-5.58	5.38-5.62	5.16-5.48	5.34-5.98	26.3-27.6	23.8024.8	26.0-27.7	25.5-26.3	27.7-30.2	23.5-25.4	24.4-30.7	27.1-29.5

No data are included for amber glass because this container was not available for testing.

TABLE 19

Yellow Cake Tests: Results by Variables, Container Geometry and Material

LOAF SHAPE

	Height (cm)								Moisture Content (%)							
	A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H
CLEAR GLASS																
Mean	6.35	6.70	6.02	7.38	6.64	---	---	---	25.00	26.50	24.17	24.67	29.20	---	---	---
Std. Dev	.47	.32	.36	.20	.43	---	---	---	1.71	1.39	1.72	1.20	1.57	---	---	---
Range	6.04-6.89	6.49-7.07	5.60-6.23	7.19-7.58	6.22-7.07	---	---	---	23.4-26.8	24.9-27.4	22.2-25.4	23.5-25.9	27.5-30.6	---	---	---
AMBER GLASS																
Mean	6.03	6.77	6.63	7.27	6.45	---	---	---	24.20	25.70	24.40	26.77	29.33	---	---	---
Std. Dev	.26	.61	.31	.41	.22	---	---	---	2.45	2.25	----	5.48	----	---	---	---
Range	5.73-6.20	6.07-7.15	6.35-6.96	6.80-7.57	6.23-6.66	---	---	---	21.7-26.6	23.5-28.0	23.6-25.9	23.6-33.1	28.1-31.2	---	---	---
THRMST POLY																
Mean	5.93	5.98	6.28	7.06	7.01	---	---	---	25.97	25.90	25.93	25.43	29.07	---	---	---
Std. Dev	.37	.06	.52	.12	.15	---	---	---	1.17	1.89	3.02	3.00	1.45	---	---	---
Range	5.53-6.27	5.92-6.03	5.94-6.88	6.99-7.20	6.89-7.18	---	---	---	25.1-27.3	25.2-26.9	23.9-29.4	22.8-28.7	27.6-30.5	---	---	---
POLYSULFONE																
Mean	6.59	6.41	6.38	6.37	7.14	---	---	---	24.93	25.13	24.80	23.37	26.57	---	---	---
Std. Dev	.11	.14	.16	.19	.19	---	---	---	1.21	.12	1.57	2.29	1.29	---	---	---
Range	6.49-6.70	6.32-6.58	6.20-6.49	6.16-6.53	6.92-7.28	---	---	---	23.8-26.2	25.0-25.2	23.4-26.5	21.8-26.0	25.1-27.5	---	---	---

No data are included for F, G, and H; loaf shape did not have these points.

TABLE 20

Yellow Cake Tests; Results by Variables, Container Geometry and Material

TABLE 20

Yellow Cake Tests; Results by Variables, Container Geometry and Material

SQUARE SHAPE

	Height (cm)								Moisture Content (%)							
	A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H
CLEAR GLASS																
Mean	2.59	3.59	3.15	3.63	4.97	---	---	---	28.30	29.40	26.40	21.33	30.0	---	---	---
Std. Dev	.13	.11	.22	.42	.02	---	---	---	.61	.50	.72	1.06	1.40	---	---	---
Range	2.50-2.73	3.51-3.71	2.95-3.38	3.25-4.08	4.96-4.00	---	---	---	27.6-28.7	28.9-29.9	25.8-27.2	20.2-22.3	28.6-31.40	---	---	---
AMBER GLASS																
Mean	2.57	3.70	3.14	3.59	4.52	---	---	---	26.57	28.77	27.63	21.67	31.47	---	---	---
Std. Dev	.20	.28	.48	.25	.31	---	---	---	.46	1.02	1.54	.49	.78	---	---	---
Range	2.44-2.82	3.43-3.98	2.61-3.56	3.44-3.88	4.21-4.83	---	---	---	26.3-27.1	27.6-29.5	26.6-29.4	21.1-22.0	30.6-32.1	---	---	---

No data are included for F, G, and H; square shape did not have these points.

No data are included for thermoset polyester and polysulfone; these containers were not available for testing.

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