COOKING SYSTEM INTERACTIONS: COMPATIBILITY OF ENERGY SOURCE AND CONTAINER MATERIAL

by

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Housing, Interior Design, and Resource Management

(ABSTRACT)

A laboratory experiment was performed to investigate the interaction between container material and energy source. The energy sources used include: conventional electric coil, gas flame, induction, solid element, and electric resistance coil under glass-ceramic. The container materials investigated include: thin gauge aluminum, heavy gauge aluminum, glass-ceramic, thin gauge porcelain-on-steel, and heavy gauge stainless steel with thick aluminum heat core. Crepes were prepared to determine the browning pattern for each cooking system (combination of energy source and container material). Water was used as a test medium for both speed of heating and retained heat tests. Duncan Multiple Range Tests were performed to determine significant differences between systems, and a General Linear Models Procedure was used to assess the contribution made by each variable on variances between systems.

When speed of heating, and retained heat are desired, the important variable was the cooktop. The induction, gas flame, and conventional electric coil boiled water

more quickly, and the solid element and the electric resistance coil under glass-ceramic retained the most heat. When even browning is desired, the choice of cookware is important. Heavy gauge aluminum and heavy gauge stainless steel with a thick aluminum heat core produced the most even browning. Systems that performed all tests well include the conventional electric coil paired with heavy gauge aluminum or heavy gauge stainless steel with thick aluminum heat core cookware.

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CHAPTER I

INTRODUCTION AND STATEMENT OF THE PROBLEM

Introduction and Justification

Consumers are faced with many choices when considering top-of-the-range cooking. Several cooktop types are available: gas, conventional coil, solid element, glass-ceramic, induction, and others. Choices also need to be made about each cooktop type individually. For example, glass-ceramic cooktops may be constructed with different heat source types and different formulations and thicknesses of glass-ceramic -each with different properties of heat transfer. Solid elements may be unprotected, thermally protected, or thermostatically controlled (E.G.O., n.d.).

Another choice that must be made when doing top-of-the-range cooking is the type of cookware to be used. Many types of cookware are available and there are also many factors that affect the performance of cookware. Some general characteristics, however, can be applied to all cookware types. For example, Wilson (1976) stated that cookware should have straight sides, flat bottoms, and tight fitting covers.

In addition, some specific requirements of cookware need to be met if it is to be used on certain cooktop types. For example, the induction range requires that cookware impart a certain level of resistance to the flow of electric current if it is to be used on the induction cooktop. This limits one's choice to cast iron, some forms of stainless steel, or porcelain-on-steel cookware (Garrison and Brasher, 1982; Jenn-Air, 1985a). The solid element range performs best when the cookware is perfectly flat (Jenn-Air, 1985b; E.G.O., n.d.). The quality of the pans can influence the results of each cooktop type, as illustrated by Scheidler (1987). Scheidler stated that the influence of pan quality on boiling time is more important than the influence of different glass-ceramics when tested with pans of the same quality. In other words, the quality of the pan is more important than the formulation of glass-ceramic.

In the mid-1800's, gas became available to consumers for cooking on a geographically limited basis, and has remained popular since. Before this time, choices for top-of-the-range cooking were limited to wood or coal (Cowan, 1983). Around 1910, electric ranges with top-of-the-range units were made available. Some models had solid elements, and others had electric coils. Eventually, the solid element lost its popularity and the electric coil remained as the one choice for top-of-the-range cooking with electricity in the United States. Solid element cooktops remained popular in Europe, however, and throughout the years underwent several improvements. In recent years, an interest in European kitchen design again popularized the solid element cooktops in the United States (Jenn-Air, 1985a). The glass-ceramic cooktop was introduced in 1966, but never achieved a great market share. Smooth-top range sales peaked in 1975 with 7.4% of the total range market share (Merchandising, 1980).

Recently there has been a reappearance of the glass-ceramic cooktop in the U.S. marketplace generally in the form of black glass-ceramic. In 1972, the first induction cooktop was marketed for the home (Andrews, 1980). Today several companies market an induction range.

When consumers' choices for top-of-the-range cooking were limited to a gas burner or electric coil, the type of cookware used was not as important as it is today. Almost any relatively flat bottomed cookware would perform satisfactorily. Today, however, consumers must have a more extensive set of criteria to evaluate the compatibility of cooktops and cookware so that they are able to make informed choices.

An appliance, such as a range or a cooktop, is a major purchase, and almost without exception entails a large expenditure for a family. According the U. S. Bureau of the Census, the average wholesale price of an electric range was $278, and the average wholesale price of an electric cooktop was $177 in 1985 (Fairchild, 1987). Since this is a sizeable investment, the consumer should be motivated to give thoughtful consideration to the selection of appliance features which can contribute to the saving of time and impact expected performance. In 1974, the U.S.D.A. estimated the life expectancy of a gas range to be 13 years, and the life expectancy of an electric range to be around 12 years. Table 1 shows the life expectancies of gas and electric ranges as reported in "A Portrait of the Appliance Industry"

Table 1
Life Expectancies of Gas and Electric Ranges

Type of Appliance	Life Expectancy (Years) Low	Medium	High
Ranges, Free Standing, Electric	13	15	19
Ranges, Built-In, Electric	13	15	20
Ranges, Free Standing, Gas	11	15	18
Ranges, Built-In, Gas	13	16	19

Source: A Portrait of the U.S. Appliance Industry, 1987.

published by Appliance in September 1987.

As a result of the long life expectancy, the purchaser may have to live with the cooktop selected for several years. Therefore, much thought should be put into the purchase decision. Cookware is also very expensive, and is a product that once purchased will be used for several years. Therefore, a good deal of thought should go into the purchase making decision for this product also.

Ideally, cookware should possess certain characteristics which would make it compatible with all cooktop types because:

1. Manufacturers often market more than one type of cooktop. They also may market or recommend cookware that is compatible with these cooktops. If cookware were available that would meet the criteria required for compatibility with all cooktops, the process of marketing cookware could be simplified.
2. Consumers sometimes move to new kitchens, or occasionally replace their ranges. As a result of the choices in cooktop types and the characteristics inherent in some of these, consumers may find their present cookware unsatisfactory.
3. When consumers purchase new cookware, they may find that the performance with their existing cooktop is not what they expected, as a result of their new cookware being manufactured of a material or with a

design different from their previous pieces.

The results of this study will be useful for consumers who want to compare appliance operating time, the resulting browning patterns, and the ability to use retained heat that results when certain cookware materials are combined with certain cooktop types.

Information based on independent research is difficult for the consumer to obtain. However, this information is essential if the consumer is to be able to objectively compare the different types of cookware/cooktop combinations.

Professional home economists will also benefit by receiving the results of this study. Home economists are often asked questions by consumers regarding the compatibility of cooktops and cookware. The results of this study will provide home economists and consumers with some objective measure for comparing the different characteristics of cookware and cooktops.

In summary, the need for this study is based on the following: There are many options available when choosing a cooktop type or selecting cookware. In addition, there are limitations to be considered when combining certain cookware with certain cooktop types. Cookware and cooktops are major purchases, with long life expectancies, requiring much information and thought when making purchase decisions and during use. However, consumers and professional home economists often find it difficult to obtain information based on independent research to aid in this decision making process.

Problem Statement

The research problem and the objective of this study were as follows: What is the result of combining cookware of different construction characteristics with cooktops of different design characteristics? This objective was met by observing the resulting performance when cookware of different materials is combined with different cooktop types. Specifically, it was necessary to:

1. Select a sample of cookware constructed of different materials and thicknesses. The items selected were representative of types of cookware available in the marketplace and were compatible with as many cooktop types as possible.
2. Select a sample of cooktop types based on market representativeness or innovativeness.
3. Analyze results of tests designed to show the outcome of interactions between cooktops and cookware. The characteristics compared were:
   a. evenness of heating.
   b. speed of heating.
   c. heat retention.

CHAPTER II

REVIEW OF LITERATURE AND THEORETICAL FRAMEWORK

Review of Literature

Introduction

The literature review explores published and unpublished literature pertaining to the construction of certain cooktop and cookware types, the physical principles observed, related research, and variables that affect the cooking system.

The literature review outlines a description of the factors that affect browning patterns, speed of heating, and ability to retain heat.

Physical Principles Under Investigation

Heat is transferred through a material by conduction. The rate of heat conduction is proportional to the temperature difference between the two sides of the material and to the area through which the heat is to be transferred. The rate is inversely proportional to the thickness of the material between the two sides. The proportionality constant relating these factors to heat transfer rate is called thermal conductivity, which varies from one material to another. Thus the following equation expresses the rate of heat conduction:

$$\text{Heat Conducted Per Second} = \frac{(K \times \text{area} \times (\text{temperature difference})}{\text{thickness}}$$

The thermal conductivity, K, for a given material is, thus, the amount of heat conducted per unit time through a unit area of material one unit thick across which there is a temperature difference of one degree. In specific units, it might be the number of kilocalories per meter per second per Celsius degree.

The equation above gives insight into but cannot be used directly to quantify the heat conducted per second in the cooking systems under investigation in this study. It must be realized that the rates of heat transfer are continuously changing depending on many factors such as the temperature difference between the source of heat and the cookware, the difference in temperature between the outside of the cookware and the inside of the cookware, and the amount of surface area touching between the energy source and container material.

The specific heat of a substance is the amount of heat needed to raise the temperature of a unit mass of the substance 1 degree C. If the specific heat and quantity of a substance are known, the amount of heat needed to be added or removed from a substance to change its temperature a fixed amount can be calculated. This calculation follows:

$$\text{Heat Needed to Change Temperature} = \text{mass} \times \text{specific heat} \times \text{temperature change}$$

The above physical principles will provide a base of knowledge that will help explain the phenomenon that may develop during testing (Table 2 illustrates how the above

Table 2

Interrelationships Between Physical Phenomena and Laboratory Observations

Physical Phenomenon	Laboratory Observation
Heat Conduction	Area of contact between the cooktop and cookware will affect the rate of heat conducted
	Thickness of the cookware will influence the rate of heat conducted
	Thermal conductivity of the cookware material and the material of the cooktop will influence the rate of heat transfer
Heat Loss	Mass of the cooktop and the cookware will influence the rate at which the temperature changes
	Specific heat of the cooktop material and the material of cookware will affect the rate of temperature change
	Specific heat of the test medium will affect the rate of temperature change

physical principles impact performance).

The Cooking System

The process of cooking can be viewed as a system. The primary components which will affect the cooking of a particular food have been included in this system and are designed to operate together (Amana, 1977; Scheidler, 1987). These are:

- -Cooking surface
- -Heating element/type
- -Cooking vessel/pot
- -Temperature control system

Independent Variables

The type of cooktop and cookware are the throughputs and processing vector in this system and constitute the independent variables of the study.

Cookware

The design and the inherent characteristics of the construction material are factors that determine the performance characteristics of cookware.

Design. The bottoms of the pans should be flat (Van Zante, 1964; Peters and Hunt, 1977; E.G.O., n.d.). Goessler (1987) stated that cookware should have flat, stable bottoms if it is to be used on glass-ceramic cooktop. Schott (1984) stated that performance on the CERAN glass-ceramic cooktop is related to the "flatness" of the cookpots. Scheidler and Schaupert (1988) stated that in order to distribute the energy generated by the induction cooktop, the pan used should be of a material of sufficient heat conductivity to avoid hot spots and a large enough gauge to assure sufficient mechanical stability. A cookpot not only needs to be flat when cool, but also when heated. When the material used in construction of a cookpot expands and distorts and the center of the pan bottom moves away from the energy source, it is called pan base movement by Scheidler and Schaupert (1988). This limits one's choices for cookware material to glass-ceramic or some form of heavy gauge metal that will stay flat and stable (Goessler, 1987).

Two tests often used to determine if cookware has a perfectly flat bottom are the ruler test (Jenn-Air, 1985a; Amana, 1977), and the cooking test (Jenn-Air, 1985a). Test procedures are outlined below:

Ruler Test --
1) Place the edge of the ruler across the bottom of the pan.
2) Hold up to the light.
3) Check to see that no light is visible under the ruler.

Cooking Test --
1) Put 1 inch of water into the utensil.
2) Place utensil on the cooking surface. Turn control to the HI setting.
3) Observe the bubble formation to determine the heat distribution. If the bubbles are uniform across the utensil, the utensil will perform satisfactorily. If the bubbles are not uniform, the bubbles will indicate the hot spots.

The sides of cookware should be straight or slightly tapered in order to conserve heat (Wilson, 1976). Each cookpot should have a cover and each one should fit snugly to form a vapor seal within the utensil whenever food is being cooked (Wilson, 1976; Thermador / Waste King, 1984).

Thickness of the pan's bottom is very important (Jenn-

Air, 1985a) because speed of conduction is directly related to gauge. A thin gauge cookpot conducts heat quickly in the vertical plane but with poor evenness in the horizontal plane. A thick gauge cookpot conducts heat more slowly and more evenly in the vertical and horizontal planes. The heavier the gauge of the pan, the more heat the material will hold (Garrison and Brasher, 1982) and the greater the possibility of even cooking performance.

Researchers at Jenn-Air (1985a) have stated that the size of cookware should be compatible with the size of the cooking unit being used. Picking a pot too small for the conventional coil element will result in wasted energy, heat transferring into the kitchen, and the possibility of having spill-overs burn onto the drip pan. A pot too large can trap heat under a coil element -- and built up heat may shorten the element's life. Thermador / Waste King (1984) stated that a pot should not extend more than one inch beyond the edge of the solid element and should have a perfectly flat bottom. When large pots do not meet these standards, the use of a high heat setting produces heat that becomes excessive and may result in damage to the cooktop. If a pot sits on the edge of a glass-ceramic cooktop, direct contact is reduced, and less heat is conducted from the surface. This can cause the glass to break. Too large or too small a utensil will cause a solid element to cycle on and off.

Researchers at Jenn-Air (1985a) have pointed out that the induction cooktops are the most tolerant of large pots but some reject utensils that are too small. (Because induction coils produce heat in the utensil as it sits on the cooktop surface, stray objects that have the proper amount of resistance to electric current, such as spoons, might accidentally be heated. Therefore induction cooktops are equipped with sensors to detect small objects, and do not allow heating to occur.)

Capacities of cookware are stated in terms of brimful maximums, though for all practical purposes, pots and pans hold only 3/4 of this amount (Wilson, 1976). Frying pan sizes are determined by the top diameter measurement. The important dimension is the bottom diameter; it should fit the element or at least not extend more than one-inch beyond it on all sides.

Inherent Characteristics of Cookware Materials. Aluminum conducts heat evenly and quickly, and is quick to respond to temperature change. Aluminum has a high coefficeint of expansion; it expands a lot for a given temperature change. Therefore, even heavy gauge cookware will warp and buckle on the bottom (Van Zante, 1964). Aluminum is an excellent conductor of electrical current, but induction cooktop manufacturers have chosen to install sensors to detect materials that offer little resistance to the flow of electrical current because they heat too quickly (Jenn-Air, 1988).

Copper is a good conductor of heat and is often applied to the bottoms of cookware (Van Zante, 1964). Like aluminum, however, copper is a good conductor of electric current, and will produce heat too quickly and will not work with the induction cooktop, because of the sensors used in the cooktop (Jenn-Air, 1985a).

Iron is a fair conductor of heat and is a good absorber of radiant heat. Once iron is heated to the desired temperature, it holds the heat (Thermador / Waste King, 1984). Iron offers resistance to electric current and will produce heat when used on the induction cooktop (Garrison and Brasher, 1982).

Steel is iron with carbon chemically dissolved in it. It is a poor conductor of heat and is prone to hot spots (Garrison and Brasher, 1982). Steel also resists electric current enough to be used on the induction cooktop (Jenn-Air, 1985a).

Stainless steel is made by adding chromium and nickel to steel. It does not conduct heat evenly and produces hot spots (Garrison and Brasher, 1982). Ehrenkranz and Inman (1973) claimed that stainless steel should be covered with aluminum or copper to prevent hot spots. The Jenn-Air use and care manual for the solid element cartridge "Model A105" contains the information that stainless steel utensils will evenly distribute heat if constructed of tri-ply (three layers of material, usually stainless steel combined with other metals such as aluminum or copper). Some forms of stainless steel can be used on the induction cooktop.

Heat resistant glass and glass-ceramic are poor conductors of heat but absorb radiant heat readily. These materials have high resistance to the flow of electric current and therefore are unsuitable for use on the induction cooktop (Garrison and Brasher, 1982).

Some cookware actually has several layers of materials sandwiched together. This is called two-ply, tri-ply, or bottom-clad construction (Wilson, 1976). This is done to maximize the benefits of certain characteristics of different materials.

Cooktops

The following descriptions of variables will help illustrate the characteristics that will affect performance.

Energy source. All cooktops must provide a source of heat energy which is transferred into food by conduction, convection, or radiation. Energy is provided via an easily transported medium such as natural gas or electric current and is transformed into a useable form of heat by means of a gas flame or electric resistance. All of these systems for producing heat have different performance characteristics. For example, a gas flame provides useable heat more quickly than an electric resistance unit.

Method of heating. Heat transfers from one body to another in one of the following ways: conduction, convection, or radiation.

Conduction is the transfer of heat by means of collision from molecule to molecule in the material (Long, 1980).

This type of heat transfer requires that the two objects touch (Garrison and Brasher, 1982). Conduction occurs each time a pan of water is heated on the surface unit of a range, as heat from a gas burner or electric element in direct contact with the pan sets the metal molecules of the pan in motion. They in turn set the water molecules in motion. This molecular motion, called heat, is given to the water in the pan and is transferred by conduction. Hewitt (1971) defines conduction as the transfer and distribution of thermal energy from molecule to molecule within a body. The more surface area available for contact between the container material and the energy source, the more contact will occur and more heat will be transferred.

Convection is the transfer of thermal energy in a gas or liquid by means of currents in the vapor or liquid (Hewitt, 1971). The layer of water in the bottom of a pan is heated first by conduction and expands, it is forced up by the cooler denser water. The convection currents keep the water in motion while it heats. Convection plays less of a role in transfering heat from cooktop to utensil than does conduction, but it is crucial to the transfer of heat from the container to the food being heated.

Radiation is the transfer of thermal energy without a medium (Long, 1980). Jenn-Air (1985a) defines radiation as heat transfer across space from a hot surface. Radiation has a limited effect as a method of heat transfer in top-of-the-range cooking.

Dependent Variables

Performance is the output and dependent variable of this system and is the quantifiable result of combining different cooktop types and cookware. The measures of performance included browning patterns, speed of heating, and ability to retain heat.

Browning Patterns

Researchers have used a standard test to measure the evenness of heat distribution. This test requires greasing and flouring the bottom of a pan and then placing the pan over the source of heat for a specified amount of time (Peters and Hunt, 1977). Scheidler (1987) stated that good temperature distribution across the pan base, to avoid burning, was an important criterion for a cooking system.

Speed of Heating

The time required to boil water is a criterion that can be used to evaluate cooktops, and generally the shorter this time, the more highly the cooktop is rated (Schott, 1984). Scheidler (1987) stated that a short boiling time was a criterion of importance for motivating consumer purchase of a cooktop.

Retained Heat

The ability to retain heat is proportional to the mass available in the cooking system, which includes the heat source and all the components required to complete the system. McCord (1970) suggested the need for further research to determine the use of stored heat to continue cooking.

The Thermador Use and Care Manual (1984) for the "Europa" solid element cooktop states the following:

--Your new solid elements cook very much like your favorite cast iron skillet -- reaching temperature gradually, yet evenly, and holding heat longer.

--The solid element retains heat somewhat longer than the other types of electric cooking elements. You may want to turn these elements off sooner to take advantage of retained heat. The amount of residual heat depends on the quantity and type of food, the material and thickness of the pan, and the setting used for cooking.

Related Research

There have been studies conducted in the past which have looked at various aspects of cooking systems. Many of these studies were focused on energy consumption. Very little information was found that allowed comparisons between different combinations of cooktops and cookware. Table 3 summarizes the related research.

McCord (1970) evaluated time and energy consumption of water heat-up between glass-ceramic surface units and conventional electric coils. McCord used only the cooktop manufacturers' recommended cookware. Time and energy consumed were greater for the glass-ceramic surface unit than the conventional electric coil when used with the manufacturers' recommended cookware. An evaluation of different pans on the glass-ceramic cooktop indicated that flat bottom pans of materials other than the utensils that are sold as part of the glass-ceramic cooking system could be efficiently used. A medium weight aluminum saucepot required less time and

Table 3

Summary of Related Research

Researcher	Year	Cooktop	Cookware	Variables under investigation	Test Medium	Principal findings
McCord	1970	Conv. Elec Glass-Ceramic	Cooktop Manufacturers Recommended & Med / Heavy Aluminum	Time and Energy Consumption	Water	Glass-Ceramic was slower Med. Alum. pan performed well on Glass-Ceramic
Peters & Hunt	1977	Traditional "Smooth-top" Thermostatic "Smooth-top" Conv. Elec	Varied Materials & Bottom Configuration	Heat Distribution Heating Efficiency (Heat-up, maint., Cool-down)	Fat -Flour Water Oil	Stain. ST. w/ Al. clad bottom had fastest Speed on all cooktops Thermo. Smoothtop had most Even Heat
Holsapple	1982	Electric Frypans Conv. Elec	Aluminum	Browning Patterns	Potato Cakes	No significant difference in Browning

Table 3 (Continued)

Summary of Related Research

Researcher	Year	Cooktop	Cookware	Variables under investigation	Test Medium	Principal findings
Lovingood et. al.	1987	Conv. Elec Thermostatic Solid Elem. Non-Thermostatic Induction	Cooktop Manufacturers Recommended	Operating Time Energy Consumption Performance Characteristics	One Week's menu for Family of Four	difference btwn cooking systems in terms of Time and Energy Significant dofferemce im Heat Distrib.
Adams and Evans	1987	Halogen - Heat Solid Elem. Gas Burner	Cast Iron Aluminum Stain. Steel	Browning Patterns	Fat - Flour	Solid was more Even than gas

energy for water heating than the specially designed glass-ceramic utensils of similar size. However, a heavy-weight Magnalite pan required more time and energy than the compatible size Cookmate.

Peters and Hunt (1977) investigated heat distribution as well as heating efficiency of conventional electric coils and of thermostatically and non-thermostatically controlled glass-ceramic cooktops using cookware of selected materials and bottom conformation. The tests included fat-flour tests for evenness of heat distribution; water boil-up, temperature maintenance, and cool down; and oil heat-up, temperature maintenance, and cool down. In the heating of water and oil, the conventional electric range unit of similar wattage to that of the two smooth-top ranges performed best with respect to heating time and energy used with test loads. The non-thermostatically controlled smooth-top was faster and consumed less energy. In the browning test, the thermostatically controlled unit performed the better of the two smooth-top ranges, and better than the conventional electric range.

The stainless steel with an aluminum clad bottom proved to be the most effective on all ranges with respect to time and energy consumption and evenness of heat distribution. In general, stainless steel with aluminum clad bottoms did not perform significantly different than the other cookware on the thermostatically controlled smooth-top.

Holsapple (1982) looked at the browning patterns and energy consumption of electric fry pans versus conventional tubular electric range coils paired with Wear-Ever (presumably aluminum) skillets. This study was limited to these cooking systems and only one test -- browning patterns of potato cakes. There was no significant difference in browning found, however, the electric frying pan was found to be considerably more efficient with both time and money.

Adams and Evans (1985) investigated browning patterns. This study differed from the Holsapple study in that it incorporated three types of frying pans on three cooktop types. The frying pans were made of cast iron, aluminum, and enameled-steel. The test medium used was fat and flour. The cooktop types were halogenheat, solid elements, and a traditional gas burner. Infra-red scans were taken when a temperature of 200 degrees F was reached at any spot on the cooking surface of the frying pan. It was found that the halogenheat cooktop has a heat distribution better than a typical solid element and markedly better than a gas burner.

Lovingood, Bentley, Lindstrom, and Walton (1987) compared cooking systems consisting of conventional electric coils, thermostatically controlled solid elements, non-thermostatically controlled solid elements, and induction cooktops, using the manufacturers recommended cookware. The cooktops were compared with respect to 1) the time the user interacts with the appliance; 2) appliance operating time; 3) appliance energy utilization; 4) other characteristics of performance such as evenness of heating, operation at low settings, responsiveness to change in control setting, and ease of cleaning. The tests included preparing items from the Association of Home Appliance Manufacturers (AHAM) Menu for Range Energy Testing and other items as appropriate to meet the objectives of the study. It was concluded that food preparation with any of these cooking systems is not markedly different in terms of energy or cooking time, but such factors as food characteristics, evenness of heating, and effect of thermal mass on temperature change do vary.

Summary of Related Research

The process of cooking has been viewed as a system, and researchers have taken this into account and have adapted their methodologies to include this idea. Studies have also been conducted that looked at performance factors such as speed of heating, user interaction, ability to retain heat, energy consumption, and browning patterns. Some studies have even compared different cooktop types combined with different cookware. However, there is little research that compares performance factors such as speed of heating, browning patterns, and retained heat as it is affected by the interaction of different cookware materials and the difference in the source of heat, as this study does. The results of this study will allow consumers, educators, and others to have a source of information that will guide them in their selection of the combination of cooktops and cookware.

Theoretical Framework

The focus of this study -- cooktop/cookware interaction and the resulting performance (Figure 2) is a subset of a larger system -- input, throughput, and output, which is the cooking system (Figure 1). The larger system uses food and power source as an input, and this leads into the cookware/cooktop processing vector which yields the performance results. This study focuses on the final two stages of this system (cooktop/cookware processing vector, and the resulting performance). The performance factors observed are considered to be objective indicators of food quality and user satisfaction, because they are similar to tasks performed by consumers.

The basic aim of science is to explain natural phenomena. Such explanations are called theories (Kerlinger, 1973). A theory, as defined by Kerlinger, is:

> a set of interrelated constructs (concepts), definitions, and propositions that present a systematic view of phenomena by specifying relations among variables, with the purpose of explaining and predicting the phenomena

By combining Figure 2, the theoretical framework of this study and the model with Kerlinger's definition of a theory, the goal of this study can be conceptualized. The goal was to predict and explain the interaction of energy source and container material.

The cooktop type and the type of cookware used were the inputs into the subsystem. A sample of each cookware

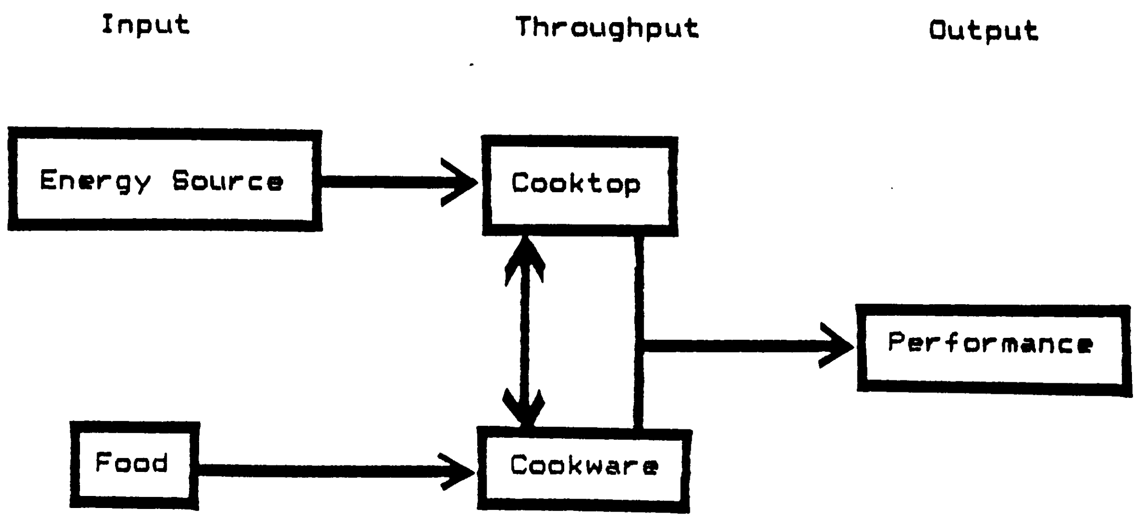


Figure 1

Cooking System

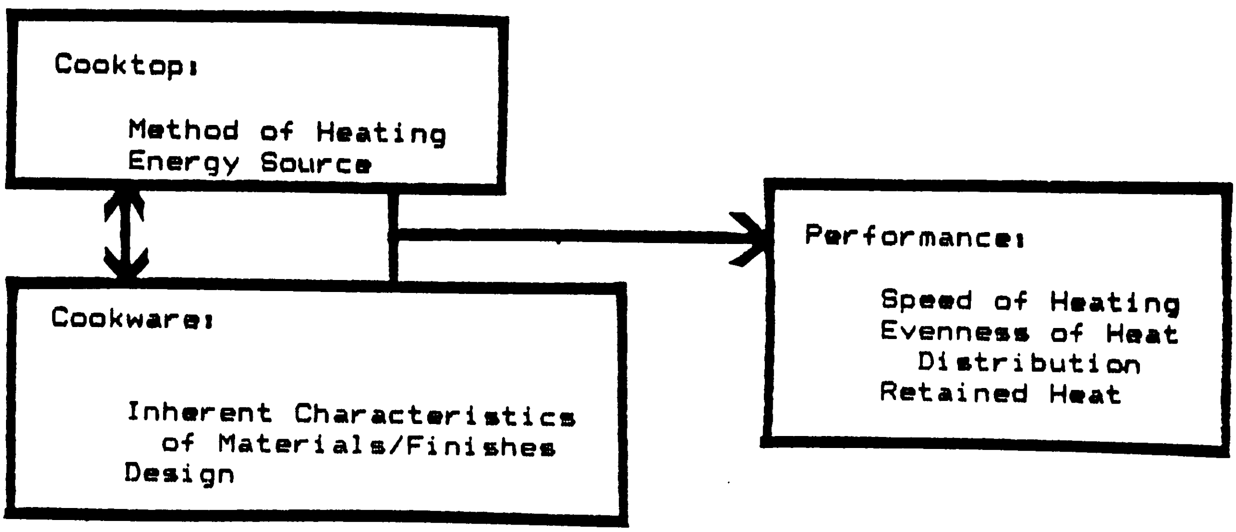


Figure 2

Theoretical Framework

type was tested on each cooktop, whenever possible. Some cookware will not work with all cooktop types. For example, glass-ceramic, aluminum, and some forms of stainless steel will not work on the induction cooktop.

Therefore, the cooking system (cooktop and cookware) was the independent variable for each test and the dependent variables were the outputs (speed of heating, ability to retain heat, and browning patterns).

Hypotheses

There are very few research results available to consumers to substantiate the recommendations made to them. Some suggestions are based on sound theory but the documentation is minimal or non-existent. Therefore, this study was designed to provide quantitative information about the relative effect of combining different container material with different sources of energy. Based on accepted scientific principles and the small amount of empirical information available, the following hypotheses have been formulated.

The first group of hypotheses are based on the difference in the construction characteristics of the cookware, and how it influences performance.

<u>Hypothesis 1</u>: The gauge of the cookware will affect speed of heat transfer. Therefore, the thin gauge aluminum and thin gauge porcelain on steel cookware will heat quickly and boil water more rapidly.

<u>Rationale:</u> A thin gauge pan will heat faster than a heavy gauge pan. As the thickness of the pan material is

directly proportional to the rate of heat transfer, therefore, the rate of heat conducted is greater in a thin gauge pan.

<u>Hypothesis 2:</u> The heavier the gauge of cookware, the more evenly the heat will be distributed. Therefore, the heavy gauge aluminum and the heavy gauge stainless steel with thick aluminum heat core will have the best pattern of heat distribution.

<u>Rationale:</u> The heavier the gauge of cookware, the more time it takes for heat to transfer from one side of the cookware to the other. Therefore, the heat will have time to spread more in the horizontal plane when a heavy gauge utensil is being used.

The following hypotheses are based on the difference in the design characteristics of the cooktops, and how it influences performance.

<u>Hypothesis 3:</u> The greater the mass and specific heat of the heating system, the greater the time required for the rate of heat transfer to the utensil to become appreciable. Therefore, the solid element and the electric resistance coil under glass-ceramic will take longer to heat up and cool down than the induction, conventional electric, or the gas flame.

<u>Rationale:</u> The more mass an object possesses, the longer it will take for that object to heat up, and to lose heat once it is heated. The specific heat of the material will also impact the amount of heat needed to change the temperature. Mass and specific heat both influence the heat needed to change temperature.

<u>Hypothesis 4:</u> Cooktops in which the heating element is

> separated from the pan by intervening space or material will require a longer time for appreciable heat transfer and therefore a longer time to gain or lose heat. Therefore, the electric resistance coil under glass-ceramic and the solid element will take longer to heat up and once heated longer to lose heat than the conventional electric coil, induction, or gas flame.

Rationale: The process of transferring heat from the source of its generation to the place of utilization takes time. When electric resistance is not needed to produce heat, or is used to produce heat directly in the cooking container, the heat generated is immediately available for heating the cookware and its contents, therefore increasing speed.

CHAPTER III

METHODOLOGY

Empirical Model

The empirical model (Figure 3) shows the independent and dependent variables under investigation in this study.

Operational Definitions

The following operational definitions of dependent variables were used in this study:

<u>Browning Pattern</u>

The browning pattern is the visible and quantifiable result of applying heat to a frying pan containing crepe batter. This browning pattern was quantified by recording five readings from each crepe (center of crepe plus center of four quadrants) with a reflectance meter, which compared the resulting color to a standard and thus allows an objective way of comparing different levels of browning.

<u>Time-to-Boil</u>

The time-to-boil is the amount of time required to heat one liter of water from 21$\pm$1 degree C to 98 degrees C

<u>Retained Heat</u>

The amount of time that is required for one liter of water placed in the cooktop / cookware to drop 10 degrees C after reaching the boiling point once the energy source is no longer energized.

INDEPENDENT VARIABLES:

Energy Source

a. Conventional Electric Coil

b. Solid Element

c. Electric Resistance Coil under Glass-Ceramic

d. Magnetic Induction

e. Gas Flame

Container Material

a. Med./Heavy Gauge Aluminum

b. Thin Gauge Aluminum

c. Heavy Gauge Stainless Steel with thick Aluminum Heat Core

d. Thin Gauge Porcelain-On-Steel

e. Glass-Ceramic

DEPENDENT VARIABLES:

Performance Factors

a. Time to Boil

b. Browning Patterns

c. Retained Heat

Figure 3 - Empirical Model

Design of the Study

The purpose of this study was to examine performance characteristics when different cooktops and cookware types are combined as a system. The dependent variables were the performance factors -- browning patterns, speed of heating, and ability to retain heat. The experimentally manipulated independent variables were cooktop type (energy source) and cookware (container material). See Table 4 for matrix outlining the design of the study.

Equipment

Cooktops

The cooktops used in this study were chosen to represent different types of cooking surfaces available to consumers in the marketplace (See Table 5).

The conventional electric coil range was chosen because G.E. has the largest market share of electric ranges and because the energy source is a Calrod unit used by many electric range manufacturers. The solid element cartridge was chosen because the solid elements used are E.G.O. units which are typical of non-thermostatic, thermally protected solid elements available in the United States market. The black glass-ceramic and the induction units were selected because they are current production models and are typical of what is available in the United States market.

Cookware

The cookware used in this study was chosen to represent

Table 4

Design of the Study

Cooktop Type

	Gas	Electric			
			Resistance		Electro-Magnetic
Cookware		Convent. Coil	Solid Element	Elec. Resis. Coil under Glass-Ceramic	Induction
Aluminum (med/hea)					X
Aluminum (thin)					X
S. Steel (med/hea) w/ heat core					
Porc.-on-St.					
Glass Ceramic					X

Table V

Cooktops Used

Conventional Electric Coil	General Electric Model JB600G 6-inch, 1325 watt 8-inch, 2350 watt
Solid Element	Jenn-Air Cartridge (Model A105) 6-inch, 1500 watt 8-inch, 2000 watt
Electric Resistance Coil under Glass-Ceramic	Jenn-Air Cartridge (Model A120) 6-inch, 1200 watt 8-inch, 1600 watt
Gas	Hardwick Model CPD 9843 KA659AG Burner size 10,000 BTU
Induction	Jenn-Air Cartridge (Model A130) Small Unit, 1400 watt Large Unit, 1800 watt

different types of base materials, popular with manufacturers and consumers. These cookware types are all available in the market place. A 1-1/2 - 2 quart sauce pot and an 8 -10 inch frying pan of each type were used. Descriptive information is given in Table 6. The gauge is indicated to the nearest thousandth of an inch, and was measured at the center of the pan. The shapes of the cookware are illustrated in Appendix A, and were classified into the following categories: bow, straight, complex, straight/slight bow, and straight/angled. Size was measured as the distance across the top of the frying pan, and was the brimful capacity for the sauce pans. The degree of flatness was an objective measure and ranged from 1, perfectly flat, to 5, very distorted (complex and concave direction of distortion is indicated). The contact area is the amount of surface area available for contact, assuming perfect flatness, and is measured in square inches.

Measuring Devices

The same set of measuring devices was used throughout the study. Specific activities were timed using a Mylan stopwatch, model no. 204 BD. Ambient temperature (wet and dry bulb) was measured using an Arthur H. Thomas Co. thermometer and relative humidity was calculated using these readings. Atmospheric pressure was measured using a Princo nova full range barometer. The temperature of the water was measured using a Fisher mercury-in-glass thermometer, graduated in 2 degree increments from -20 to 120 degrees C. A

Table 6

Cookware Used

Frying Pans

Thin gauge aluminum	Wear Ever Gauge: .104 Shape: Bow Size: 10" Round Degree of Flatness: 4 Concave Contact Area 38.5
Med/Thick gauge aluminum	Magnalite Model - Wagner Ware "Sidney" 4508-D Gauge: .165 Shape: Straight Size: 10" Round Degree of Flatness: 2 Convex Contact Area: 60.1
Thin gauge porcelain-on-steel	Genoa Model - 24C Gauge: .060 Shape: Complex Size: 8" Round Degree of Flatness: 5 Concane Contact Area: 39.2
Medium/Heavy gauge Stainless Steel with Heat Core	Sears Model - 391.5088 Gauge: .225 Shape: Bow Size: 10" Round Degree of Flatness: 2 Concave Contact Area: 34.5
Glass-Ceramic	Corning Model - "Cookmate" KA - SK10 Gauge: .160 Shape: Straight Size: 10" Square Degree of Flatness: 1 Flat Contact Area: 67.24

Table 6

Cookware Used (Continued)

Sauce Pans

Thin gauge aluminum	Wear Ever Model - 38012 Gauge: .050 Shape: Straight (Angled Side) Size: 1.8 L. Degree of Flatness: 5 Concave Contact Area: 24.9
Med/Thick gauge aluminum	Wear Ever Model - "Centennial" Gauge: .155 Shape: Straight (Moderate Curve) Size: 1.85 L. Degree of Flatness: 2 Convex Contact Area: 26
Thin gauge porcelain-on-steel	Genoa Model - 15 C Gauge: .067 Shape: Complex Size: Degree of Flatness: 1 Concave Contact Area: 14.2
Medium/Heavy gauge Stainless Steel with thick Aluminum Heat Core	Sears Model - "New Dimension" 391.5088 Gauge: .224 Shape: Slight Bow Size: 2.1 L. Degree of Flatness: 2 Convex Contact Area: 27.1
Glass-Ceramic	Corning Model - "Cookmate" KA-6P-3 Gauge: .153 Shape: Straight Size: 2.85 L. Degree of Flatness: 1 Flat Contact Area: 37.8

Hunter Color Difference Reflectance Meter was used to determine the extent of browning as measured by the percentage of light reflected from the surface of the browned crepes. (See Table 7 for instruments used and variables measured.)

The data for this study were collected in the Virginia Polytechnic Institute and State University College of Human Resources household equipment laboratory during Winter Quarter 1987 - 1988.

Temperature in the laboratory ranged from 23 to 25 degrees C throughout the study but was usually 24 degrees C. The relative humidity averaged 71 percent; however, it ranged from 42 to 96 percent. Barometric pressure was normally near 715 millimeters, but ranged from 701 mm to 721 mm.

Pretests

A series of pretests was conducted to determine the general range of time required to bring water to a boil and to produce browning patterns on the crepes and refine the procedures.

Additional tests were conducted in order to become acquainted with the procedures to be followed and the variables to be measured. This pretest also familiarized the researcher with the controls and operation of the cooktops and the general performance characteristics of the cookware.

General Procedure

Table 7

Variables Measured and Instruments Used

Variables	Instrument	Unit of Measure
Environment:		
Temperature	Thermometer	Degree Celsius
Relative Humidity	Psychrometer	Percent Relative Humidity
Atmospheric Pressure	Barometer	Millimeters Mercury
Dependent:		
Speed of Heating	Stopwatch	Minutes
	Thermometer	Degree Celsius
Browning Pattern	Reflectance Meter	Percent Different from a Standard
Retained Heat	Stopwatch	Minutes
	Thermometer	Degree Celsius

Each test was performed under the following guidelines:

- All water used in this study was tap water from the Blacksburg water system and was conditioned to 21 $\pm$ 1 degree C. Blacksburg water is naturally about 3 grains hard and undergoes no treatment but chlorination, fluoridation, and purification.

- The stopwatch was started and the cooktop control turned to HIGH for tests using water and MED-HI for tests using crepes.

- When the test was completed, the stopwatch and the cooktop control were turned OFF.

- In the time to boil and retained heat tests, guidelines for measuring temperature were as follows. As indicated by pretests, insert the thermometer under the cover when 90% of the pretest time has elapsed. If the temperature is not within 10 degree C (time-to-boil) or 2 degree C (retained heat), remove the thermometer. After 30 seconds (time-to-boil) or 1 minute (retained heat), repeat the procedure. Continue at the same interval until the target temperature is reached.

The tests were conducted in random order in the household equipment laboratory at Virginia Tech. Each combination of cookware and cooktop was written on a piece of paper and placed in a bowl. At the beginning of each testing session, pieces of paper corresponding to the number of teats scheduled were pulled out. The tests were conducted in such a way as to allow cool-down for the cooktops and cookware, and to protect the freshness of the crepe batter. This random selection was intended to reduce procedural variables that could be introduced by the investigator. Ambient temperature was monitored but was not controlled. All tests were replicated twice, for a total of three tests per combination of energy source and container material and performance factor.

Each day a data sheet was completed (Appendix B). This sheet includes the tests to be conducted, the amount of time required, or the resulting browning patterns. Room temperature, humidity, and atmospheric pressure were recorded at the start of each data gathering session. Although the atmospheric data will not be used for statistical analysis, it will help describe the environmental conditions during data collection.

Specific Procedure

The specific procedure followed to evaluate the performance of each cooktop/cookware combination is as follows:

Evenness of Browning

1. Spray the frying pan with a light coating of "All Natural" Pam non-stick cooking spray.

2. Place three or four droplets of water in a cool frying pan and place on a cool cooktop, turn the control to MED-HI.

3. Record ambient condition information on Data Collection Sheet (Appendix B).

4. When the water evaporates, pour 1/4 cup of crepe mixture (Blender Crepes; See Appendix C for recipe) into the frying pan, quickly tilt the frying pan to cover the entire bottom.

5. Place the frying pan on the cooktop to be evaluated.

6. Start the stopwatch.

7. Brown the crepe on the first side for 2 minutes.

8. Discard the first crepe and repeat steps 4 - 7 three consecutive times, for a total of three crepes.

9. Turn the unit to OFF, and remove the frying pan from the unit.

10. Record the browning pattern of the bottom of the crepe, on the data collection chart in Appendix B, by using the procedure specified by the reflectance meter manufacturer (See Appendix D for chart demonstrating the location of the points where readings were taken).

Speed of Hheating

1. Place one liter of tap water in the pan to be evaluated (21$\pm$1 degree C).

2. Place the cover on the pan, and then place the pan on the cooktop to be evaluated (See Table 5 for information on which unit is to be used.)

3. Record the water temperature.

4. Turn the unit to HIGH and start the stopwatch.

5. As determined by pretests, when the water is approaching boiling, place the thermometer under the cover with the bulb near, but not touching, the bottom.

6. When the temperature reaches 98 degrees C, turn the unit to OFF, stop the stopwatch, and record the time-to-boil readings on the data collection sheet (Appendix B).

Retained Heat

1. Place one liter of water (21$\pm$1 degree C) in the saucepan to be tested, cover and place on the cooktop.

2. Turn the unit to HIGH.

3. Heat the water to boiling.

4. After the boiling temperature is reached, cover, turn the unit to OFF, start the stopwatch.

5. When the temperature reaches 88 degrees C, stop the stopwatch, and record time on the data collection chart (Appendix B).

Note: This test may be combined with the test to measure speed of heating.

Delimitation of the Study

Due to money and time constraints and limited availability of the equipment to be tested, certain boundaries, or delimitations were established. These were:

1. Five types of cookware were evaluated.
2. Five cooktop types were evaluated.
3. Three performance factor tests were conducted on each cooktop/cookware combination.
4. Two replications of each test were conducted.
5. Cookware compatible with each cooktop were used; therefore, the aluminum and glass-ceramic cookware could not be used on the induction cooktop.

Data Analysis

Since the purpose of this study was to measure the evenness of heat distribution and to measure the differences in the amount of time required to boil water and to cook on retained heat when different combinations of cooktop and cookware are used, the following calculations were performed:

1. The mean and range of the browning pattern, time to boil, and the time for the temperature to drop were calculated for each combination of cookware and cooktop type.

2. A General Linear Models Procedure was performed so that the reliability of the tests could be monitored and so that the contributions that each variable had on the variation in performance could be assessed.

3. A Duncan's Multiple Range Procedure was performed in order to aid in ranking the systems and determining significant differences between systems.

The results of these tests were tabulated and compiled in chart form so that the variability could be measured and any trends found. The statistical tests used in analyzing the data were selected in order to facilitate answering the following questions:

1. Will the thin gauge aluminum and thin gauge porcelain on steel heat water faster than the heavy gauge aluminum, heavy gauge stainless steel, and glass-ceramic?

2. Will the heavy gauge aluminum, heavy gauge stainless steel, and glass-ceramic frying pans have better patterns of browning than the thin gauge porcelain-on-steel, and aluminum frying pans?

3. Will the electric resistance coil under glass-ceramic and solid element cooktops retain more heat than the conventional electric coil, the gas flame, and the induction cooktops?

4. Will the conventional electric coil, the electric resistance coil under glass-ceramic, and the solid element cooktop heat more slowly than the gas flame and the induc-

tion cooktop?

5. What is the optimum combination of cookware and cooktop?

6. Is it possible to find one type of cookware that is satisfactory with all of the cooktops?

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The interaction of energy source and container material were investigated in this laboratory study. The energy sources included were conventional electric coil, gas flame, solid element, induction, and electric resistance coil under glass-ceramic. The container materials were thin gauge aluminum, heavy gauge aluminum, thin gauge porcelain-on-steel, glass-ceramic, and heavy gauge stainless steel with thick aluminum heat core. The interactions were quantified by examining selected performance factors -- browning patterns, time-to-boil, and time-to-lose heat (retained heat). Each test was performed three times for each cooking system (combination of energy source and container material). Browning patterns were determined from crepes, and water was used as the test medium for the time-to-boil and the retained heat tests. The Hunter Color Difference Meter was used to measure the amount of light reflected, therefore quantifying the browning patterns, and a mercury-in-glass thermometer was used to measure temperature. (Data charts are presented in Appendix E).

In this chapter are presented the results of the browning pattern, time-to-boil, and retained heat tests -- the dependent variables. Each section is focused on a dependent variable and includes the following sub-parts: general trends, significant differences, relationships of the results to the hypotheses, and generalizations based on the hypotheses. Throughout this chapter, the following abbreviations will be used:

1. Energy Source -

   CCOIL - Conventional Coil

   GASFL - Gas Flame

   INDUC - Induction

   SOLID - Solid Element

   GCERM - Electric Resistance Coil Under Glass-Ceramic

2. Container Material -

   TALUM - Thin Aluminum

   HALUM - Heavy Aluminum

   SSWHC - Heavy Gauge Stainless Steel With Thick Aluminum Heat Core

   GCERM - Glass-Ceramic

   TPORC - Thin Porcelain-on-Steel

Browning Patterns

General Trends

Variations in browning were apparent in all of the tests. Some of the crepes were evenly browned, while others had a distinctive ring around the edge, and still others had obvious hot spots.

The investigation of browning pattern, as conducted in this study, was a multi-step process. First, a General Linear Modeling Procedure was conducted on all of the data readings in order to determine which variables influenced the levels of browning. Next, two statistical tests were conducted to compare the influence of each variable on browning patterns. Finally, the two statistical tests were combined so that a ranking of cooking systems, based on even heat distribution, could be obtained.

A General Linear Models Procedure for "impact of browning" is presented in Table 8. This procedure illustrates the impact of the combination of different cooktops (energy source) with different frying pans (container material) on the level of browning, not the browning patterns of crepes. The high F-Value (18.54) and a PR > F of .0001 reveal a statistically significant model. The variables source, material, and position (location of reflectance meter reading) are significant at the ($p < .05$) level. This means that the cooktop type, material of the frying pan, and location of the reflectance meter reading all are important in determining the observed browning. By dividing the Type III Sum of Squares into the Model Sum of Squares, it can be determined how much influence each variable in the system impacts browning. The energy source contributes 12.8% (4942/38551) of the variation in browning. The container material contributes 35.9% (13853/38551) of the variation in browning in addition to the amount already explained by the energy source. The position (location of reflectance meter reading) contributes 2.2% (832/38551) of the variation in

Table 8

General Linear Models Procedure for
Impact of Browning

Source	DF	Sum of Squares	Mean Square	F Value	PR > F	R-Square	C.V.
Model	57	38551.4946	676.34	18.54	.0001	.795271	14.152
Error	272	9924.4554	36.49		Root Mse		Brown Mean
Corrected Total	329	48475.9500			6.0404		42.6670

Source	Df	Type I SS	F Value	PR > F	DF	Type III SS	F Value	PR > F
Source	4	7708.7662	52.82	.00001	4	4942.5141	33.86	.00001
Material	4	13853.0329	94.92	.00001	4	13853.0329	94.92	.00001
Position	4	774.5616	5.31	.00004	4	832.5310	5.70	.00002
Source * Material	13	6236.5882	13.15	.00001	13	6236.5882	13.15	.00001
Source * Position	16	1961.4174	3.36	.00001	16	1982.4746	3.40	.00001
Material * Position	16	8017.1282	13.73	.00001	16	8017.1282	13.73	.00001

Contrast	DF	SS	F Value	PR > F
Center vs Outside	1	825.7881	22.63	.00001

browning in addition to the browning already explained by the energy source and container material.

In addition, the interaction of source and material, source and position of reflectance meter readings, and the interaction of material and location of reflectance meter readings are significant in influencing level of browning at the ($p < .05$) level. Again, by dividing the Type III Sum of Squares into the Model Sum of Squares, it can be seen that the interaction of source and material account for 16.2% (6236/38551) of the variation in browning not already explained. The interaction of source and location of reflectance meter reading accounted for 5% (1982/38551) of the variation in browning not already explained, and the interaction of material and location of reflectance meter reading account for 21% (8017/38551) of the variation in browning not already explained. This procedure also compares the variation of browning between the four outside quadrants and the reading from the center (See contrast "center vs. outside", Table 8). This contrast observation is also statistically significant at the $p < .05$ level.

The previous procedure indicated the variables that influenced levels of browning. The next test is the first of two statistical procedures that help explain the <u>browning pattern</u>. A General Linear Models Procedure for the variable "Range of Outside Readings" is presented in Table 9. The F Value of 2.75 and a PR > F level of .0023 indicates a statistically significant test. The R-Square value of 0.568

TABLE 9

General Linear Models Procedure
for variable "Range of Outside Readings"

Source	DF	Sum of Squares	Mean Square	F Value	PR > F	R-Square	C.V.
Model	21	1143.590	54.457	2.75	.0023	.568	46.325
Error	44	869.920	19.771		Root MSE	Outside Range Mean	
Corrected Total	65	2013.510			4.445		9.600

Source	DF	Type 1 SS	F Value	PR > F	DF	Type III SS	F Value	PR > F
Combo	21	1143.590	2.75	.0023	21	1143.590	2.75	.0023

indicates that 56.8% of the variation in browning patterns can be explained by this procedure.

A Duncan's Multiple Range Test for the variable "Range of Outside Readings"; data reading points 1-4, the outer edge, is presented in Table 10. (See Appendix D for Location of Reflectance Meter Readings.) This table groups systems (combinations of energy source and container material) into like categories. Groupings with the same letter designation are not significantly different from each other. The systems are grouped in ascending order with the system having greatest variation in range of readings at the top of the list. This table illustrates great variation in the means of outside reflectance readings between systems.

Another way to assess the evenness of browning is to compare the means of the reflectance meter readings from the four outside quadrants to the reflectance meter reading from the center. A General Linear Models Procedure for the variable "Range of Readings -- Outside vs. Inside" is presented in Table 11. The F Value of 16.50 and a PR > F level of .0001 indicates a statistically significant test. The R-Square value of 0.887 indicates that 88.7% of the variation in browning patterns can be explained by this procedure. Table 12, Duncan's Multiple Range Test for the Variable "Outside vs. Inside Readings", groups systems (combinations of energy source and container material) into like categories. Groupings with the same letter designation are not significantly different from each other. Rankings are

Table 10

Duncan's Multiple Range Test for n = 3 crepes
variable investigated"Range of Outside Readings"

Duncan Grouping (1)						Mean (difference in % of light reflected)	Source	Material
			A			18.867	SOLID	TPORC
			A					
	B		A			17.867	CCOIL	GCERM
	B		A					
	B		A	C		16.233	SOLID	GCERM
	B		A	C				
	B	D	A	C		14.167	GCERM	HALUM
	B	D	A	C				
E	B	D	A	C		13.133	SOLID	TALUM
E	B	D	A	C				
E	B	D	A	C		12.333	INDUC	TPORC
E	B	D	A	C				
E	B	D	A	C	F	10.733	GASFL	TALUM
E	B	D		C	F			
E	B	D		C	F	10.100	GASFL	HALUM
E	B	D		C	F			
E	B	D		C	F	9.533	SOLID	HALUM
E		D		C	F			
E		D		C	F	9.033	GASFL	TPORC
E		D		C	F			
E		D		C	F	9.033	GCERM	SSWHC
E		D		C	F			
E		D		C	F	8.700	GCERM	GCERM
E		D		C	F			
E		D		C	F	8.633	GCERM	TPORC
E		D			F			
E		D			F	7.200	GCERM	TALUM
E		D			F			
E		D			F	6.967	CCOIL	HALUM
E		D			F			
E		D			F	6.567	CCOIL	TPORC
E		D			F			
E		D			F	6.367	CCOIL	TALUM
E		D			F			
E		D			F	6.233	INDUC	SSWHC
E		D			F			
E		D			F	5.967	CCOIL	SSWHC
E		D			F			
E		D			F	5.867	GASFL	SSWHC
E					F			
E					F	4.333	GASFL	GCERM
					F			
					F	3.300	SOLID	SSWHC

Alpha = .05

(1) Systems with the same number are not significantly different

Table 11

General Linear Models Procedure
for variable "Range of Readings - Outside vs Inside"

Source	DF	Sum of Squares	Mean Square	F Value	PR > F	R-Square	C.V.
Model	21	7680.569	365.741	16.50	.0001	.887	45.922
Error	44	975.573	22.172		Root MSE		Outside vs. Inside
Corrected Total	65	8656.142			4.710		10.254

Source	DF	Type 1 SS	F Value	PR > F	DF	Type III SS	F Value	PR > F
Combo	21	7680.569	16.50	.0001	21	7680.569	16.50	.0001

Table 12

Duncan's Multiple Range Test for n = 3 crepes
variable investigated: "Outside vs. Inside Readings"

Duncan Groupings (1)		Mean (difference in % of light reflected)	Source	Material
	A	38,450	GASFL	GCERM
	A			
	A	38.192	SOLID	GCERM
	B	29.275	CCOIL	GCERM
	C	18.592	CCOIL	TPORC
	C			
D	C	14.183	SOLID	TPORC
D				
D	E	9.900	INDUC	TPORC
D	E			
D	E	8.942	GASFL	TALUM
D	E			
D	E	7.458	GASFL	SSWHC
D	E			
D	E	7.233	GCERM	SSWHC
D	E			
D	E	7.233	GASFL	TPORC
D	E			
D	E	5.692	GCERM	HALUM
	E			
	E	5.175	GCERM	TPORC
	E			
	E	4.892	SOLID	TALUM
	E			
	E	4.658	SOLID	HALUM
	E			
	E	4.333	GCERM	TALUM
	E			
	E	4.067	CCOIL	HALUM
	E			
	E	4.050	GCERM	GCERM
	E			
	E	4.033	GASFL	HALUM
	E			
	E	2.592	INDUC	SSWHC
	E			
	E	2.267	CCOIL	TALUM
	E			
	E	2.267	SOLID	SSWHC
	E			
	E	2.100	CCOIL	SSWHC

Alpha = .05

(1) Systems with same letter are not significantly different

in ascending order with the greatest range in means at the top of the list.

Table 13 combines the results of observations from "Range of Outside Readings" and from " Outside vs. Inside Readings", by using the R-Square values and Duncan's Multiple Range Rankings. This combination is achieved by multiplying the R-Square value by an assigned number (1 = least variance - 22 = most variance) of the Duncan Ranking for both tests. These values are added and then re-ranked. Thus, this combination weights the systems based on their position in the two rankings and the amount of explained variation each test possesses. Furthermore, a cut-off point in the middle will distinguish even browning from uneven browning. The right half of the list will be the more even heating systems and the left half will be the less even heating.

The General Linear Modeling Procedure for impact of browning, Table 8, indicated that the choice of container material was more important than the choice of energy source in determining the level of browning. The ranking of browning patterns by systems reveal that 75% of the heavy aluminum and 80% of the heavy gauge stainless steel with thick aluminum heat core pans were in the bottom right of the rankings, indicating good patterns of heat distribution. The thin aluminum pans ranked equally on both sides of the cut-off point for even distribution. The glass-ceramic and thin gauge porcelain-on-steel tended towards the left of the

Table 13

Ranking of Bronwning Patterns
by system
(Higher Socre Indicates More Uneven Browning)

Uneven Browning Systems			Even Browning Systems		
Source	Material	Score	Source	Material	Score
SOLID	GCERM	30.0	SOLID	HALUM	16.0
CCOIL	GCERM	29.6	GCERM	TPORC	15.5
SOLID	TPORC	28.5	GASFL	SSWHC	15.0
INDUC	TPORC	24.7	GASFL	HALUM	12.9
GASFL	TALUM	23.3	GCERM	TALUM	12.2
GCERM	HALUM	21.4	GCERM	GCERM	11.5
GASFL	GCERM	21.0	CCOIL	HALUM	10.7
CCOIL	TPORC	20.9	INDUC	SSWHC	6.3
GCERM	SSWHC	19.8	CCOIL	TALUM	6.1
SOLID	TALUM	19.1	CCOIL	SSWHC	3.2
GASFL	TPORC	18.3	SOLID	SSWHC	2.5

Note -- The scores for this chart are derived by Adding the results of Multiplying the R-Square value of the General Linear Models Procedrue by the ranking value from a Duncans Multiple Range Test for the two tests "Range of Outside Readings" and "Range of Readings - Outside vs. Inside" list, indicating poor patterns of heat distribution (75% and 80%, respectively).

The conventional electric coil (60%) and electric resistance coil under glass (60%) tended to score with good patterns of heat distribution. The induction cooktop ranked on both sides of the cut-off line, and produced a noticeable ring around the center of the outer quadrants on the tested crepes. The heavy gauge stainless steel with the thick aluminum heat core produced markedly better patterns of heat distribution than the thin gauge porcelain-on-steel on the induction cooktop. The solid element and gas flame resulted in poor patterns of heat distribution.

These results can be explained as follows: The glass-ceramic frying pan conducts heat more rapidly in the vertical plane than in the horizontal. Therefore, the solid element, conventional electric coil, and gas flame did not produce heat in the center of this pan. The thin gauge porcelain-on-steel and the thin aluinum expands and distorts when heated, thus creating different areas of contact which affect the browning pattern. The heavy aluminum and stainless steel with heat core encourage even heating by slowing the rate of heat transfer from the energy source to the bottom of the inside of the frying pan, thus allowing more time for heat to spread in the horizontal plane. This occurs because the rate of heat transfer is inversely proportional to the thickness of the gauge of the pan. The thicker gauge pan One reason for the difference in performance or uneven patterns of heat transfer may be the lack of contact between heat source and cookware in the center sections the center of the conventional electric coil, the solid element, or the gas flame. This could explain the variation in browning between the center and outside quadrants. The glass-ceramic frying pan yielded acceptable performance only on the electric resistance coil under glass-ceramic, possibly due to the similarities of materials and their respective properties of heat transfer.

Relationship to Hypothesis

Hypothesis: The heavier the gauge of cookware, the more evenly the heat will be distributed, Therefore, the heavy gauge aluminum and the heavy gauge stainless steel will have the best pattern of heat distribution.

Findings. The heavy gauge aluminum pan and the stainless steel with thick aluminum heat core generally had good heat distribution. The thin aluminum did not rank consistently as having a good or poor pattern of heat distribution. The thin gauge porcelain-on-steel and the glass-ceramic frying pans had poor patterns of heat distribution. Therefore, the hypothesis is accepted.

Time-to-Boil

General Trends

Means for time-to-boil for each cooking system are given in Table 14. Using the Duncan's Multiple Range Test for the variable "Time-to-Boil", several systems were found to be significantly different from others. The solid element and

Table 14

Duncan's Multiple Range Test for
Variable "Time-to-Boil"
(1 liter of water 21 - 98 degree C)

Duncan Grouping (1)			Mean (minutes)	Source	Material
	A		10.827	GCERM	TALUM
	B		9.623	SOLID	TALUM
	C		9.257	SOLID	TPORC
	C				
D	C		9.060	GCERM	TPORC
D					
D	E		8.813	GCERM	HALUM
	E				
	E		8.670	GCERM	GCERM
	F		7.987	GCERM	SSWHC
	G		7.237	SOLID	GCERM
	H		6.677	CCOIL	TPORC
	I		6.307	CCOIL	TALUM
	I				
	I		6.270	CCOIL	GCERM
	I				
J	I		6.217	INDUC	TPORC
J	I				
J	I	K	6.047	GASFL	TPORC
J		K			
J	L	K	5.947	GASFL	GCERM
	L	K			
M	L	K	5.820	SOLID	HALUM
M	L	K			
M	L	K	5.797	GASFL	SSWHC
M	L	K			
M	L	K	5.773	CCOIL	HALUM
M	L				
M	L		5.730	SOLID	SSWHC
M	L				
M	L		5.717	INDUC	SSWHC
M					
M	N		5.577	GASFL	TALUM
M	N				
M	N		5.550	GASFL	HALUM
	N				
	N		5.367	CCOIL	SSWHC

Alpha = .05

(1) Systems with the same letter are not significantly different.

the glass-ceramic cooktops consistently took longer to heat water to a boil. Eight of the 10 possible readings fell within the top half of the ranking of time-to-boil means when ranked in descending order.

Time-to-boil was related to three factors: energy source, container material, and the interaction of the energy source and container material. This information is presented in

Table 15, General Linear Models Procedure for "Time-to-Boil". The high F Value (326.70) indicate that the model and test are significant at the PR > F level of .0001. Source, material, and the interaction of source and material all influence the time-to-boil, as indicated by the high PR > F value of .0001 for each variable individually.

By dividing the Type III Sum of Squares into the Model Sum of Squares, it can be shown that 63.6% (107/168) of the variation in time-to-boil can be explained by the energy source used. The container material used will explain 17.8% (30/168) of the variation in time-to-boil not explained by the energy source. The interaction of energy source and container material will explain 17.2% (29/168) of the variation in time-to-boil not already explained by energy source and container material. The R-Square value of .994 indicates that 99.4% of the variation in time-to-boil can be explained by this statistical procedure.

Table 16, Duncan's Multiple Range Test for variables "source" and "material", ranks time-to-boil data while hold-

Table 15

General Linear Models Procedure
for variable "Time-to-Boil"

Source	DF	Sum of Squares	Mean Square	F Value	PR > F	R-Square	C.V.
Model	21	168.348	8.017	326.7	.0001	.994	2.234
Error	44	1.080	.025		Root MSE		Boil Mean
Corrected Total	65	169.428			.157		7.012

Source	DF	Type 1 SS	F Value	PR > F	DF	Type III SS	F Value	PR > F
Source	4	109.957	1120.28	.0001	4	107.770	1098.00	.0001
Material	4	29.719	302.78	.0001	4	29.719	302.78	.0001
Source * Material	13	28.673	89.88	.0001	13	28.673	89.88	.0001

Table 16

Duncan Multiple Range Tests across Variables
"Time-to-Boil"

Holding Energy Source Constant
Alpha = .05

Group	Mean (minutes)	Source
A	9.07	Glass-Ceramic
B	7.53	Solid Element
C	6.08	Conv. Coil
C		
C	5.97	Induction
D	5.78	Gas Flame

Holding Container Material Constant
Alpha =.05

Group	Mean (minutes)	Material
A	8.08	Thin Aluminum
B	7.45	Thin Porc.-on-Steel
C	7.05	Glass-Ceramic
D	6.49	Heavy Aluminum
E	6.12	Stain St. w/heat core

ing energy source or container material constant. In other words, the information is presented across one variable while the other variable is held constant. This information showss how energy sources compare to each other, or how materials compare to each other. At the Alpha = .05 level, all variables yield significantly different results when viewing the variable source and material as a group, with the exception of the induction and the conventional electric coil which are not significantly different. The gas flame was consistently able to bring water to a boil more quickly.

The electric resistance coil under glass-ceramic, and the solid element consistently took the longest time to bring the water to a boil. This can be explained by the method utilized in creating heat in the energy source. Since it is by electric resistance, it requires time for the heat to travel from the resistance coil to a useable form for cooking. In the electric conventional coil, the electric resistance coil is closer to the surface touching the bottom of the pan; therefore, it heats more quickly than the solid element or the electric resistance coil under glass-ceramic. The induction cooktop and the gas flame provide heat that is instantly available for use.

Scheidler and Schaupert (1988) states that "pan bottom movement" influences "time-to-boil". Pan bottom movement occurs as follows: As the sauce pot heats, thermal expansion causes the center of the pan bottom to move away from the energy source, reducing the efficiency of the system and increasing time-to-boil. This explains the poor performance of the thin gauge aluminum and thin porcelain-on-steel, since their thin gauge construction may have allowed pan bottom movement to occur.

Another important factor affecting the results is the fact that the saucepans were of different shapes. This might explain why water boils faster with the stainless steel with a heat core than the thin porcelain-on-steel saucepan on the induction cooktop (The thin porcelain-on-steel pan has a more narrow base than the stainless steel with a heat core). The rate of heat transfer is proportional to the amount of surface area available for contact with the energy source.

Table 17 is a cross-tabulation of the average number of minutes required to bring one liter of water to 98 degrees C from 21 degrees C with each possible combination of energy source and container material. This table provides a quick reference for comparing time-to-boil results for each individual cooking system. The XXX's represent combinations of container materials and energy sources that were not possible due to incompatibilities.

Relationship to Hypothesis

Hypothesis: The gauge of the cookware will affect speed of heat transfer. Therefore the thin gauge aluminum and thin gauge porcelain-on-steel cookware will heat quickly and boil water more rapidly.

Findings. The thin gauge porcelain-on-steel and the

Table 17

Average Time-to-Boil

1 liter of water from 21 C to 98 C

CONTAINER MATERIAL

	Heavy Gauge Alum.	Stain. St. w/ heat core	Porc. St. Thin Gauge	Glass-Ceramic	Thin Gauge Alum.
ENERGY SOURCE					
Conv. Coil	5.76	5.37	6.68	6.27	6.31
Gas Flame	5.57	5.80	6.05	5.95	5.58
Glass-Ceramic	8.81	7.99	9.06	8.67	10.83
Induction	XXXX	5.72	6.22	XXXX	XXXX
Solid Element	5.82	5.73	9.26	7.24	9.62

XXXX's - indicate systems that are imposslible due to incompatibilities thin gauge aluminum took the longest time to bring water to a boil (Table 16). This may be explained by the fact that when thin gauge metals are heated they expand and distort. When this change occurs, the ability of the pan to make contact with the energy source is reduced, therefore decreasing the efficiency of the system. Since these results were inconsistent with the hypothesis, this hypothesis was not accepted.

Hypothesis: Cooktops in which the heating element is separated from the pan by intervening space or material will require a longer time for appreciable heat transfer and therefore a longer time to gain or lose heat. Therefore, an electric resistance coil under glass-ceramic and the solid element will take longer to heat up, and once heated, longer to lose heat, than the conventional electric coil, induction, or gas flame cooktops.

Findings. The solid element and the electric resistance coil under glass-ceramic cooktops did take longer to bring water to a boil. These cooktops have heating elements separate from the pan by intervening space or materials. The conventional electric coil and the induction cooktop took less time to bring water to a boil than the solid element and the glass-ceramic cooktop, however, there was not a significant difference between the two. The gas flame consistently was able to bring the water to a boil more quickly than any other cooktop. Since the data supports the hypothesis, it is accepted.

Hypothesis: The greater the mass and specific heat of the heating system, the greater the time

> required for the rate of heat transfer to become appreciable. Therefore, the solid element and the electric resistance coil under glass-ceramic will take longer to heat up and cool down than the induction, conventional electric, or the gas flame cooktops.

Findings: The systems that contain large amounts of mass, such as the solid element and the electric resistance coil under glass-ceramic, did take longer to bring water to a boil. The conventional electric coil and the induction cooktop took less time to bring water to a boil than the solid element and the glass-ceramic cooktop, however there was not a significant difference between the two. The gas flame consistently was able to bring the water to a boil more quickly than any other cooktop. Since the data support the hypothesis, it is accepted.

Retained Heat

General Trends

Means for retained heat for each cooking system are given in Table 18. Using the Duncan's Multiple Range Test for the variable "Retained Heat", several systems were found to be significantly different from others.

The ability to retain heat was related to three factors: energy source, container material, and the interaction of the energy source and container material. This information is presented in Table 19, General Linear Models Procedure for "Retained Heat". The high F Value (569.82) and PR > F of .0001 indicate that the test is significant. Source,

Table 18

Duncan's Multiple Range Test for Varialble
"Retained Heat"
(1 liter of water 98 - 88 degree C)

Duncan Groupings (1)	Mean (minutes)	Source	Material
A	30.880	GCERM	TALUM
B	30.100	GCERM	HALUM
C	28.073	SOLID	TALUM
D	27.147	GCERM	SSWHC
E	25.900	GCERM	TPORC
E			
E	25.890	SOLID	TPORC
F	23.920	SOLID	HALUM
G	23.087	SOLID	SSWHC
H	21.267	GCERM	GCERM
I	19.463	CCOIL	TALUM
I			
I	19.220	SOLID	GCERM
J	17.517	CCOIL	SSWHC
J			
J	17.360	CCOIL	HALUM
J			
J	16.817	GASFL	SSWHC
J			
J	16.787	GASFL	HALUM
K	15.530	CCOIL	TPORC
K			
K	14.910	GASFL	TALUM
L	13.787	CCOIL	GCERM
L			
M L	13.703	GASFL	GCERM
M L			
M L	13.313	INDUC	SSWHC
M			
M	12.983	GASFL	TPORC
N	11.310	INDUC	TPORC

Alpha =.05

(1) Systems with the same letter are not significantly different.

Table 19

General Linear Models Procedure
for variable "Retained Heat"

Source	DF	Sum of Squares	Mean Square	F Value	PR > F	R-Square	C.V.
Model	21	2282.056	108.669	569.82	.0001	.997	2.189
Error	44	8.391	.191		Root MSE		Retain Mean
Corrected Total	65	2290.447			.436		19.953

Source	DF	Type 1 SS	F Value	PR > F	DF	Type III SS	F Value	PR > F
Source	4	1875.756	2458.92	.0001	4	1820.834	2386.93	.0001
Material	4	281.471	368.98	.0001	4	281.471	368.98	.0001
Source * Material	21	124.829	50.35	.0001	13	124.289	50.35	.0001

material, and the interaction of source and material all influence the retained heat, as indicated by the high PR > F value of .0001. The information presented in Table 19, indicates that the variation in time-to-lose heat (retained heat) is mainly due to the energy source used; 79.6% (1820/2282) of the variation is explained by energy source. The container material used will explain 12.3% (281/2282) of the variation not already explained by the energy source. In addition, 5.5% (125/2282) of the variation in retained heat is due to the interaction of energy source and container material, not already explained.

Table 20 Duncan's Multiple Range Test for variables "source" and "material", ranks retained heat data while holding energy source or material constant. In other words, the information is presented across one variable while the other is held constant. This information tells us how energy sources compare to each other, or how materials compare to each other. At the Alpha = .05 level, all variables yield significantly different results when viewing the variable source and material as a group.

The electric resistance coil under glass and the solid element cooktops consistently retained the most heat, occupying eight of a possible 10 positions in a listing of the systems mean time-to-lose heat. The thin aluminum and thin porcelain-on-steel saucepans retained the most heat, occupying six of the top 10 positions on the ranking of retained heat systems. As a result of the thin gauge of these pans,

Table 20

Duncan's Multiple Range Test Across Variable "Retained Heat" (While holding Source or material constant)

holding "Source" constant

Alpha = .05

Group	Mean (minutes)	Source
A	27.1	Glass-Ceramic
B	24.0	Solid Element
C	16.7	Conv. Coil
D	15.0	Gas Flame
E	12.3	Induction

holding "Material" constant

Alpha = .05

Group	Mean (minutes)	Material
A	23.3	Thin Aluminum
B	22.4	Heavy Aluminum
C	19.6	Stain St. w/heat core
D	18.3	Thin Porc.-on-Steel
E	17.0	Glass-Ceramic

they may expand and distort reducing the surface area available for contact -- therefore reducing the system efficiency and requiring the system to heat longer. Since the system is on longer, more heat builds up in the system possibly increasing the time-to-lose heat. This is supported by the fact that the thin porcelain-on-steel saucepan combined with the induction or gas flame retained the least heat (neither the induction unit nor the gas flame require a flat bottom). All of the systems which retained large amounts of heat contain large amounts of mass or have heating elements separate from the pan by intervening space or material.

The gas flame and induction cooktop consistently retained the least heat. This is due to the fact that these systems do not contain large amounts of masso generate heat. Therefore, there is no heat built up in the energy source.

Table 21, Results of "Retained Heat", presents the average number of minutes it took for one liter of water to drop 10 degree C from the boiling point for each possible combination of energy source and container material. The XXX's represent combinations of container materials and energy sources that were not possible, due to incompatibilities.

<u>Relationships to Hypothesis.</u>

<u>Hypothesis:</u> The greater the mass and specific heat of the heating system, the greater the time required for the rate of heat transfer to become appreciable. Therefore, the solid element and the electric resistance coil under glass-ceramic will take longer to heat up and cool down than the induction, conventional electric coil, or the gas

Table 21

Time to Lose Heat (MINUTES)
(1 liter of water 98 C to 88 C)

ENERGY SOURCE	CONTAINER MATERIAL: Heavy Gauge Alum.	Stain. St. w/ heat core	Porc. St. Thin Gauge	Glass-Ceramic	Thin Gauge Alum.
Conv. Coil	17.36	17.52	15.53	13.79	19.46
Gas Flame	16.79	16.82	12.98	13.70	14.91
Glass-Ceramic	30.10	27.15	25.90	21.27	30.88
Induction	XXX	13.31	11.31	XXX	XXX
Solid Element	23.92	23.09	25.89	19.22	28.07

XXX - indicate systems that are not possible due to incompatabilities.

flame cooktops.

Findings. The glass-ceramic and the solid element cooktops retained more heat than the conventional coil, gas flame, or the induction cooktops. The conventional coil and the gas flame retained more heat than the induction cooktop. Since these results were consistent with the hypothesis, the hypothesis is accepted.

Hypothesis: Cooktops in which the heating element is separated from the pan by intervening space or material will require a longer time for appreciable heat transfer and therefore a longer time to gain or lose heat. Therefore, the electric resistance coil under glass-ceramic and the solid element will take longer to heat up, and once heated, longer to lose heat than the conventional electric coil, induction, or gas flame.

Findings. The glass-ceramic and the solid element cooktops retained more heat than the conventional coil, gas flame, or the induction cooktops. The conventional coil and the gas flame retained more heat than the induction cooktop. Since these results were consistent with the hypothesis, the hypothesis is accepted.

Summary of Results

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

- Distinctive browning patterns resulted with different combinations of energy source and container material. According to a General Linear Modeling Procedure, container material impacts browning more than does the energy source.

- The heavier the gauge of a metallic frying pan, the more even the heat distribution, and the more predictable the browning pattern.

- Different combinations of energy source and container material impact speed of heating (time-to-boil). A General Linear Models Procedure indicated that the energy source was the variable that had the major influence on the time-to-boil. The energy source that took the longest to bring water to a boil was the glass-ceramic followed by the solid element, the conventional electric coil and the induction (no significant difference), and the gas flame.

- The thin gauge saucepans did not take the least time to heat water, possibly due to pan base movement. The sauce pots that heated most quickly were the heavy aluminum and the heavy gauge stainless steel with thick aluminum heat core.

- The ability to retain heat was mainly due to the energy source used, as determined by a General Linear Models Procedure. The solid element and the electric resistance coil under glass-ceramic cooktops with large amounts of mass and constructed of materials of high specific heat, consistently took the longest time to lose heat.

- The cooktops in which the heating element is separated from the pan by intervening space or material took the longest to lose heat.

Discussion

In this study, different combinations of cooktops and cookware yielded different browning patterns when preparing crepes. Adams and Evans (1987) found different pattern of heat distribution, also. They found that heat distribution was more even with the solid element than the gas flame. This was consistent with the findings of this study. Peters and Hunt (1977) cited no significant differences in heat distribution when using a stainless steel with an aluminum clad bottom on a conventional electric coil vs. a stainless steel frying pan with an aluminum clad bottom or a "Cook-mate" glass-ceramic frying pan on a thermostatically or non-thermostatically controlled glass-ceramic cooktop. This is consistent with this study, as the stainless steel with an aluminum heat core frying pan worked well with all cooktops. However, the glass-ceramic combined with the electric resistance coil under glass-ceramic yielded satisfactory results. This may be due to the difference in glass-ceramic formulations, or type of electric resistance coil used in the cooktop used in this study.

McCord (1977) reported that glass-ceramic cooktops took longer than a conventional electric coil to bring water to a boil. McCord used the manufacturer's recommended cookware of aluminum and glass-ceramic. This is consistent with the findings in this study in which it was found that the cooktop influenced time-to-boil more than the type of cookware.

Peters and Hunt (1977) found that a conventional electric coil heated both water and oil more quickly than a thermostatically or non-thermostatically controlled glass-ceramic cooktop. In this study, the conventional electric coil heated water more quickly than an electric resistance coil under glass. This may be due to the fact that the electric resistance coil under glass-ceramic contains a great deal more mass to heat before heat can be utilized for cooking than the conventional electric coil. Therefore it takes longer to heat on the glass-ceramic cooktops.

CHAPTER V

SUMMARY AND RECOMMENDATIONS

Summary

Consumers are interested in the performance that result when they combine different cooktop types with different cookware. Also, there is a limited amount of literature available to consumers and professional home economists on the interaction of cooktops and cookware. Thus, this research study was designed to provide this information by comparing the resulting performance factors of different combinations of cooktops and cookware. The performance factors investigated include: browning patterns, time-to-boil, and retained heat.

The data for this study were collected at the Virginia Polytechnic Institute and State University household equipment laboratory during the winter of 1987-1988. Two repetitions of each test, for a total of three sets of data were obtained. The energy sources investigated include: conventional electric coil, gas flame, induction, solid element, and electric resistance coil under glass-ceramic. The container materials investigated include: thin gauge aluminum, heavy gauge aluminum, thin gauge porcelain-on-steel, glass-ceramic, and heavy gauge stainless steel with thick aluminum heat core. The tests: browning patterns, time-to-boil, and retained heat were conducted for each cooking system (combination of energy source and container material). Browning patterns were determined by preparing crepes and then quantifying percentage of light reflected with a Hunter Color Difference Meter. Time-to-boil and retained heat tests were conducted using water as a test medium and temperature was measured with a mercury-in-glass thermometer. Tests used in statistical analysis of the data included: General Linear Modeling Procedures, Duncan's Multiple Range tests, means, and ranges.

Conclusions

Based on the results of these tests, the major findings were:

- The choice of frying pan material has the greatest impact on browning. The heavier the gauge of cookware, the more evenly the heat will be distributed. Therefore, the heavy gauge aluminum and the heavy gauge stainless steel with thick aluminum heat core had the best pattern of heat distribution.
- The cooktops that performed with satisfactory browning include the conventional electric coil and the electric resistance coil under glass-ceramic. The induction cooktop had readings of good and poor patterns of heat distribution, depending on the gauge of the frying pan used. The gas flame and the solid element had poor heat distribution and thus poor browning patterns. Therefore, choose a cooktop with great mass and large amounts of surface area touching the bottom of the pan, if even heating is important.

- An important variable in determining time-to-boil and retained heat was the choice of materials used in the construction of the energy source. The greater the mass and specific heat of the heating system, the greater the time required for the rate of heat transfer to become appreciable. Therefore, the solid element and the electric resistance coil under glass-ceramic will take longer to heat up and cool down than the induction, conventional electric coil, or gas flame.
- The stainless steel with heat core took the least amount of time to bring water to a boil, followed by the heavy gauge aluminum, and glass-ceramic respectively. The gauge of the cookware will affect speed of heat transfer. Therefore, the thin gauge aluminum and thin gauge porcelain on steel cookware heated more quickly and boiled water more rapidly. The thin gauge porcelain-on-steel and the thin aluminum were the slowest, suggesting that factors such as pan base movement affect the rate of heat transfer.
- An important variable in determining time-to-boil, and the ability to retain heat is the design of the cooktop selected. Cooktops in which the heating element is separated from the pan by intervening space or material will require a longer time for appreciable heat transfer and therefore a longer time to gain or lose heat. Therefore, the electric resistance coil

under glass-ceramic and the solid element will take longer to heat up and once heated longer to lose heat than the conventional electric coil, or gas flame.

- Cooking systems with the thin aluminum pans retained the most heat followed by those with the heavy aluminum, stainless steel with heat core, thin porcelain-on-steel, and glass-ceramic.

Implications

Major findings of this study suggest that consumers can expect differences in performance depending on which combination of cookware and cooktop they choose.

Based on the major findings and statistical analysis, the following recommendations are made to consumers who desire to achieve the best performance from their cooking system.

1. When even browning is important, choose a frying pan of heavy gauge and an energy source of large mass that allows for even heat distribution.

2. When speed of heating is important, choose a cooktop that does not have the heating element separate from the pan by intervening space or material. Choose cookware that has a flat bottom, and is constructed of a material and gauge that will not allow distortion while heating.

3. When retained heat is important, choose a cooktop that has large mass and areas of high specific heat close to the source of heat production, and choose cookware of a

heavy gauge metal.

4. When all three performance factors are desired, (even browning, speed of heating, and retained heat), the best system would be the conventional electric coil paired with heavy gauge aluminum cookware, or cookware constructed of stainless steel with thick aluminum heat cores.

Limitations and Recommendation

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

1. Limitation. Only five specific cooktop types were used in this study: conventional electric coil, gas flame, induction, solid element, and electric resistance coil under glass.

   Recommendation. Further research is needed to determine if these findings hold true for other brands and models of cooktops. It would especially be interesting to compare performance of cooktops that incorporate different method of construction and different materials (i.e., some manufacturers of glass-ceramic cooktops use different formulations of glass-ceramic and different types of electric resistance heating elements).

   Recommendation. Further research is needed to determine how other cooktop types would perform under the same conditions (e.g., halogen heat and gas flame under glass-ceramic are available).

2. Limitation. Only five specific types of cookware were used in this study: thin gauge aluminum, heavy gauge aluminum, stainless steel with heat core, thin gauge porcelain-on-steel, and glass-ceramic.

   Recommendation. Further research is needed to determine how other materials would perform under the same conditions (e.g., cast iron, anodized aluminum, and various other cookware with different finishes and construction materials are available).

   Recommendation. Further research is needed to determine how other brands and models of cookware, and cookware with different design characteristics would perform under like conditions.

3. Limitation. The test mediums used in this study included water and crepes. It is unlikely that these are representative of the items consumers use to judge the performance of their cooking system.

   Recommendation. Further research is needed to determine the quantitative and qualitative characteristics of the foods which consumers evaluate performance.

   Recommendation. Further research is needed to determine the results of using test mediums used in previous research, such as oil and potato pancakes.

4. Limitation. It is difficult, even for the educated consumer, to determine the specifications of appliances. Many consumers may be unaware of dif-

ferences in the performance of cooktops that appear virtually the same.

Recommendation. Research is needed to determine what consumers know about top-of-the-range cooking appliances. Then educators and retailers could help consumers utilize their appliances for optimum performance.

5. Limitation. The pieces of cookware used in this study were all different, not only in material, but in size and shape. This could affect the results because the amount of surface area available for contact may be different.

   Recommendation. A special set of cookware should be obtained for testing, which holds size and shape constant so that these variables will not influence results.

As a result of the findings of this study, it can be stated that the proper combination of cookware and cooktop is important.

Cookware should have the maximum amount of surface area available for contact with the cooktop. The bottom should be as flat as possible and the gauge should be sufficient to prevent pan bottom movement.

When even browning is important, the choice of cookware is important. Choose heavy gauge cookware such as heavy gauge aluminum or heavy gauge stainless steel with a thick aluminum heat core.

When performing boiling activities, and time is important, the choice of cooktop is important. Choose one that does not have a great deal of mass surrounding the heat source. Good choices would be the gas flame, induction, or the conventional electric coil.

When cooking on retained heat is important, the choice of cooktop is important. Choose one that has a great deal of mass surrounding the source of heat. Good choices would be the solid element or the electric resistance coil under glass-ceramic.

The process of cooking can be viewed as a system, which in its simplest form is the combination of energy source and container material.

Below is a matrix outlining recommended combinations of cookware and cooktops based on the findings of this study. The purpose of this matrix is to provide consumer with the information to make the proper selection when purchasing new cooktop or cookware depending on the task or performance criteria they want to achieve. This matrix will also assist in developing acceptable cooking systems by indicating which combinations of the consumers current cooktops and cookware will yield the performance they desire. The matrix is a result of performance tests conducted for this thesis. The system recommendations all rank in the top 50% of the groupings for each test. Therefore, based on the results of this study, the following systems are recommended.

1. For even heat distribution:

Energy Source	with	Container Material
Solid Element or Conventional Electric Coil		Heavy Stainless Steel with Thick Aluminum Heat Core
Electric Resistance Coil under Glass-Ceramic		Glass-Ceramic

2. For speed of heating:

Energy Source	with	Container Material
Gas Flame or Induction or Conventional Electric Coil		Heavy Stainless Steel with Thick Aluminum Heat Core
Gas Flame or Conventional Electric Coil		Heavy Aluminum

3. For retained heat.

Energy Source	with	Container Material
Electric Resistance Coil under Glass-Ceramic or Solid Element		Thin or Heavy Aluminum or Porc.-on-steel

4. For Even Heating, Speed of Heating, and Retained Heat

Energy Source	with	Container Material
Conventional Electric Coil		Heavy Stainless Steel with Thick Aluminum Heat Core or Heavy Aluminum

REFERENCES

Adams, F. J., & Evans, O. T. (1985). 'Cooking by light' - A revolutionary approach to electric hobs. Proceedings of the 36th International Appliance Technical Conference, Madison, Wisconsin, T-1 -T-12.

Amana Refrigeration, Inc. (1977). Corning 3+1 electric ranges and cooktop demonstration guide (Form No. 7275). Amana, IA: Author.

Andrews, N. (1980). Verification tests of proposed test methods for induction cooking tops. Product Performance Engineering Division, Center for Consumer Product Technology, National Bureau of Standards.

✓A portrait of the U.S. appliance industry. (1987, September), Appliance, 45-64.

Complete step-by-step cook book. (1978). Better Homes and Gardens, Des Moines, IA,. Meredeth Corporation.

✓Cowan, R. (1983). More work for mother. New York: Basic Books, Inc.

E.G.O. Products. (n.d.). EGO solid element use and care guide (Manager of consumer Affairs). Newnan, GA: Author

Ehrenkranz, F., & Inman, L. (1973). Equipment in the home. New York: Harper and Row.

Fairchild Fact File. (1987). Household appliances, electric housewares, and home entertainment products. Fairchild Publications, New York, 11.

58Th Annual Statistical and Marketing Report. (March, 1980). Merchandising, 22-23.

✓Garrison, C., & Brasher, R. (1982). Modern household equipment. New York: McMillan Publishing.

Goessler, G. (1987). Heating systems for glass-ceramic cooktops. Proceedings of the 38th International Appliance Technical Conference, Columbus, Ohio, 111-119.

✓Hewitt, P. (1971). Conceptual physics: A new introduction to your environment. Little Brown and Co.

Holsapple, G. (1982). Browning and energy consumption in skillets on a conventional electric range and in electric fry pans. Unpublished masters thesis, The Ohio State University.

Jenn-Air Company. (1985a). Cooktops and cookpots: The compatibility story. Indianapolis, IN: Author (slide and script, and program).

Jenn-Air Company. (1985b). Use and care manual Solid element cartridge model A105 (Part No. 203569A. Indianapolis, IN: Author.

Jenn-Air Company. (1983). Use and care manual induction cooktop cartridge model A130 (Part No. 202912). Indianapolis, IN: Author.

Kerlinger, F. N. (1973). Foundations of behavioral research. New York: Holt, Rinehart, and Winston, Inc.

Long, D.D. (1980). The physics around you. Belmont, CA: Wadsworth Publishing.

Lovingood, R. P., Bentley, S. G., Lindstrom, A. B., & Walton, L. G., (1987). Innovative and conventional cooktops: Energy use, operating time, user interaction, and other characteristics of performance. Proceedings of the 38th International Appliance Technical Conference, Columbus, Ohio, 120-126.

McCord, R. A. (1970), An evaluation of selected performance characteristics of glass-ceramic covered electric units and of a conventional thermostatically controlled electric surface unit. Unpublished master's thesis, University of Tennessee, Knoxville.

Peters, C. A., & Hunt, F. E. (1977). Heat distribution and heating efficiency in selected pans on conventional glass-ceramic surfaced electric range units. Home Economics Research Journal, 5(3), 176-189.

Scheidler, H. (1987). Characteristics of glass-ceramic cooktops suitable for the U.S. market. Proceedings of the International Appliance Technical Conference, Columbus, OH, 582-592.

Scheidler, H., & Schaupert, K. (1988). The importance of suitable cookware for induction heating systems. Proceedings of the 1988 International Appliance Technical Conference, Cologne, West Germany, 185-193.

Schott. (1984). Schott information (Issue 2/1984 - ISSN 0586-7665). Federal Republic of Germany: Author.

Thermador/Waste King. (1984). Europa cooktop care and use guide (Part No. 14-30-679-90). Los Angeles, CA: Author.

U.S.D.A. Agriculture Research Service. (1974). Life expectancy of household appliances surveyed. Washington D.C.: Government Printing Office.

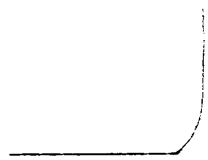
Van Zante, H. (1964). Household equipment principles. Englewood Cliffs, NJ., Prentice-Hall.

Wilson, P. (1976). Household equipment: selection and management. Boston: Houghton Mifflin Company.

APPENDICES

Appendix A

Container Material Shapes



Straight (Slight Bow)

Straight (Angled)

Bow

Straight

Complex

Appendix B

DATA COLLECTION SHEET
for Time to Boil Test

EQUIPMENT USED:

Energy Source ______________________________

Container Material ______________________________

	Test 1	Test 2	Test 3
Date	______	______	______
Investigator	______	______	______
AMBIENT CONDITIONS:			
Room Temperature Wet Bulb (Degree Celsius)	______	______	______
Dry Bulb (Degree Celsius)	______	______	______
Relative Humidity (Percent)	______	______	______
Barometric Pressure (Millimeters Mercury)	______	______	______
DATA READINGS:			
Beginning Water Temperature (Degree Celsius)	______	______	______
Ending Water Temperature (Degree Celsius)	______	______	______
Time To Boil (Minutes)	______	______	______

DATA COLLECTION SHEET
for Browning Pattern Test

EQUIPMENT USED:

Energy Source ____________________________________

Container Material ____________________________________

	Test 1	Test 2	Test 3
Date	______	______	______
Investigator	______	______	______

AMBIENT CONDITIONS:

	Test 1	Test 2	Test 3
Room Temperature Wet Bulb (Degree Celsius)	______	______	______
Dry Bulb (Degree Celsius)	______	______	______
Relative Humidity (Percent)	______	______	______
Barometric Pressure (Millimeters Mercury)	______	______	______

DATA READINGS:

	Test 1	Test 2	Test 3
Time enerty source / container material is preheated (minutes)	______	______	______
Time Crepe is in pan (minutes)	______	______	______

READINGS:

	Test 1	Test 2	Test 3
Point 1 (L Value)	______	______	______
Point 2 (L Value)	______	______	______
Point 3 (L Value)	______	______	______
Point 4 (L Value)	______	______	______
Point 5 (L Value)	______	______	______

DATA COLLECTION SHEET
for Retained Heat Test

EQUIPMENT USED:

Energy Source ______________________________

Container Material ______________________________

	Test 1	Test 2	Test 3
Date	______	______	______
Investigator	______	______	______
AMBIENT CONDITIONS:			
Room Temperature			
Wet Bulb (Degree Celsius)	______	______	______
Dry Bulb (Degree Celsius)	______	______	______
Relative Humidity (Percent)	______	______	______
Barometric Pressure (Millimeters Mercury)	______	______	______
DATA READINGS:			
Beginning Water Temperature (Degree Celsius)	______	______	______
Ending Water Temperature (Degree Celsius)	______	______	______
Time To Loose Heat (Minutes)	______	______	______

Appendix C

Recipe for
Blender Crepes

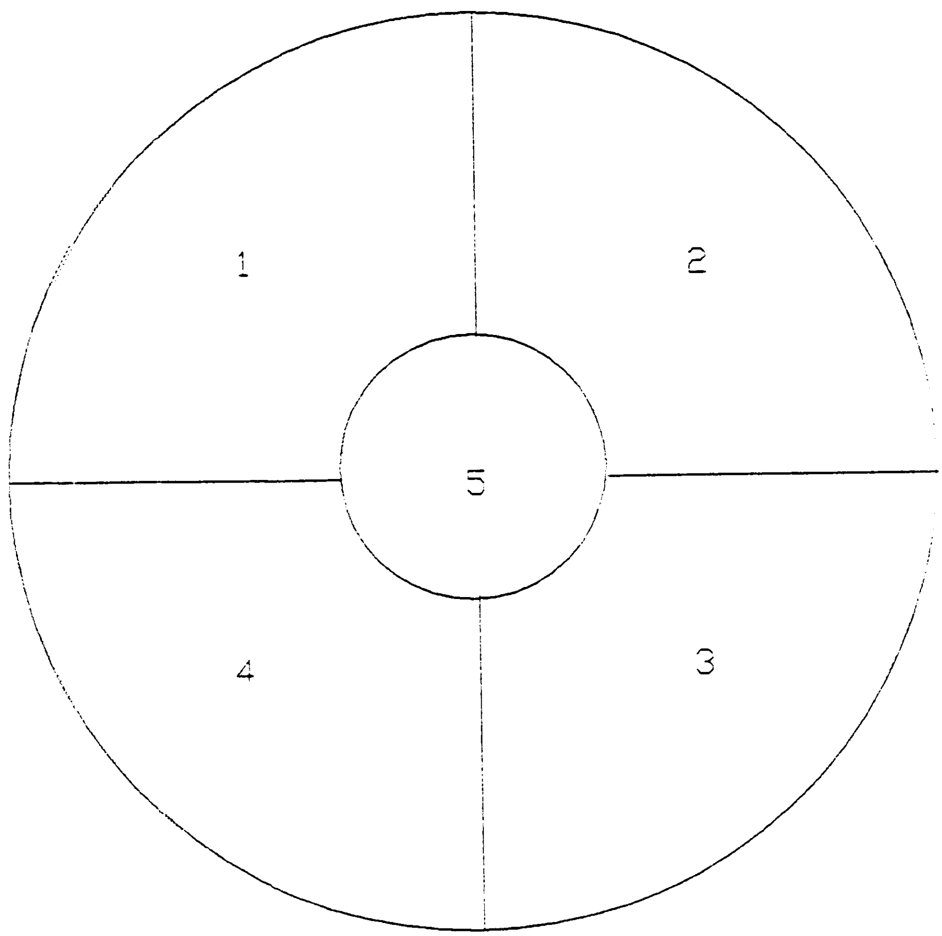
1 cup all-purpose Flour
3 Eggs
1 1/2 cups Milk
2 Tablespoons of Vegetable Oil

Put all ingredients into blender container. Cover and process at BLEND until smooth.

Note: Adapted from Better Homes and Gardens: Complete Step - by - Step Cookbook.

Appendix D

Location of Reflectance Meter Readings



Appendix E

Data from Three Replications of Browning Test

SAS

VARIABLE	MEAN	STANDARD DEVIATION	RANGE
------------ SOURCE=GCERM MATERIAL=HALUM ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	55.65333333	6.15326472	18.40000000
------------ SOURCE=GCERM MATERIAL=SSWHC ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	41.98666667	5.02008347	16.60000000
------------ SOURCE=GCERM MATERIAL=TALUM ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	56.32666667	6.57554633	19.30000000
------------ SOURCE=GCERM MATERIAL=TPORC ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	36.00666667	4.15442392	13.00000000
------------ SOURCE=INDUC MATERIAL=SSWHC ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	29.90666667	2.90233075	10.80000000
------------ SOURCE=INDUC MATERIAL=TPORC ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	28.68000000	6.30342311	21.10000000
------------ SOURCE=SOLID MATERIAL=GCERM ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	40.34666667	17.41870369	49.30000000
------------ SOURCE=SOLID MATERIAL=HALUM ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	46.66000000	5.07202411	17.50000000
------------ SOURCE=SOLID MATERIAL=SSWHC ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	36.02000000	2.28604462	7.60000000
------------ SOURCE=SOLID MATERIAL=TALUM ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	44.18000000	5.75551909	21.80000000
------------ SOURCE=SOLID MATERIAL=TPORC ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	38.58666667	10.04901322	36.30000000

SAS

VARIABLE	MEAN	STANDARD DEVIATION	RANGE
------------ SOURCE=CCOIL MATERIAL=GCERM ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	40.31333333	14.01687079	45.20000000
------------ SOURCE=CCOIL MATERIAL=HALUM ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	53.78666667	5.42070985	18.20000000
------------ SOURCE=CCOIL MATERIAL=SSWHC ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	38.04666667	5.49842402	17.60000000
------------ SOURCE=CCOIL MATERIAL=TALUM ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	54.50666667	5.85143043	19.60000000
------------ SOURCE=CCOIL MATERIAL=TPORC ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	52.66000000	11.44057941	36.20000000
------------ SOURCE=GASFL MATERIAL=GCERM ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	29.94000000	16.56781734	52.00000000
------------ SOURCE=GASFL MATERIAL=HALUM ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	59.92666667	5.07324448	17.10000000
------------ SOURCE=GASFL MATERIAL=SSWHC ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	40.50000000	4.72334627	16.70000000
------------ SOURCE=GASFL MATERIAL=TALUM ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	42.42000000	6.43341722	19.80000000
------------ SOURCE=GASFL MATERIAL=TPORC ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	41.98666667	5.02008347	16.60000000
------------ SOURCE=GCERM MATERIAL=GCERM ------------			
POSITION	3.00000000	1.46385011	4.00000000
BROWN	30.23333333	5.14138206	16.60000000

Data from Three Replicatios
of Boiling and Retained Heat Test

SAS

VARIABLE	MEAN	STANDARD DEVIATION	RANGE
------------ SOURCE=GCERM MATERIAL=HALUM ------------			
BOIL	8.81333333	0.19731531	0.36000000
RETAIN	30.10000000	0.76078906	1.52000000
------------ SOURCE=GCERM MATERIAL=SSWHC ------------			
BOIL	7.98666667	0.12342339	0.24000000
RETAIN	27.14666667	0.38682468	0.77000000
------------ SOURCE=GCERM MATERIAL=TALUM ------------			
BOIL	10.82666667	0.11930353	0.22000000
RETAIN	30.88000000	0.27784888	0.50000000
------------ SOURCE=GCERM MATERIAL=TPORC ------------			
BOIL	9.06000000	0.05291503	0.10000000
RETAIN	25.90000000	0.22516660	0.45000000
------------ SOURCE=INDUC MATERIAL=SSWHC ------------			
BOIL	5.71666667	0.20231988	0.36000000
RETAIN	13.31333333	0.18583146	0.34000000
------------ SOURCE=INDUC MATERIAL=TPORC ------------			
BOIL	6.21666667	0.08504901	0.17000000
RETAIN	11.31000000	0.46776062	0.82000000
------------ SOURCE=SOLID MATERIAL=GCERM ------------			
BOIL	7.23666667	0.17039171	0.34000000
RETAIN	19.22000000	0.20420578	0.39000000
------------ SOURCE=SOLID MATERIAL=HALUM ------------			
BOIL	5.82000000	0.31000000	0.59000000
RETAIN	23.92000000	0.31096624	0.61000000
------------ SOURCE=SOLID MATERIAL=SSWHC ------------			
BOIL	5.73000000	0.10583005	0.20000000
RETAIN	23.08666667	0.69327724	1.37000000
------------ SOURCE=SOLID MATERIAL=TALUM ------------			
BOIL	9.62333333	0.28571548	0.57000000
RETAIN	28.07333333	0.88121129	1.60000000
------------ SOURCE=SOLID MATERIAL=TPORC ------------			
BOIL	9.25666667	0.22030282	0.44000000
RETAIN	25.89000000	0.31575307	0.59000000

SAS

VARIABLE	MEAN	STANDARD DEVIATION	RANGE
------------ SOURCE=CCOIL MATERIAL=GCERM ------------			
BOIL	6.27000000	0.07000000	0.13000000
RETAIN	13.78666667	0.50934599	1.01000000
------------ SOURCE=CCOIL MATERIAL=HALUM ------------			
BOIL	5.77333333	0.03511885	0.07000000
RETAIN	17.36000000	0.46184413	0.90000000
------------ SOURCE=CCOIL MATERIAL=SSWHC ------------			
BOIL	5.36666667	0.04163332	0.08000000
RETAIN	17.51666667	0.13203535	0.26000000
------------ SOURCE=CCOIL MATERIAL=TALUM ------------			
BOIL	6.30666667	0.11718931	0.22000000
RETAIN	19.46333333	0.52880368	0.97000000
------------ SOURCE=CCOIL MATERIAL=TPORC ------------			
BOIL	6.67666667	0.09073772	0.18000000
RETAIN	15.53000000	0.51468437	1.02000000
------------ SOURCE=GASFL MATERIAL=GCERM ------------			
BOIL	5.94666667	0.32036438	0.62000000
RETAIN	13.70333333	0.08020806	0.16000000
------------ SOURCE=GASFL MATERIAL=HALUM ------------			
BOIL	5.55000000	0.05567764	0.11000000
RETAIN	16.78666667	0.30072135	0.56000000
------------ SOURCE=GASFL MATERIAL=SSWHC ------------			
BOIL	5.79666667	0.08504901	0.16000000
RETAIN	16.81666667	0.54372174	1.05000000
------------ SOURCE=GASFL MATERIAL=TALUM ------------			
BOIL	5.57666667	0.03055050	0.06000000
RETAIN	14.91000000	0.29206164	0.58000000
------------ SOURCE=GASFL MATERIAL=TPORC ------------			
BOIL	6.04666667	0.03055050	0.06000000
RETAIN	12.98333333	0.22810816	0.40000000
------------ SOURCE=GCERM MATERIAL=GCERM ------------			
BOIL	8.67000000	0.09643651	0.18000000
RETAIN	21.26666667	0.16165808	0.32000000

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