EPRI

Induction Cooking Performance and Demonstration

Technical Report

Induction Cooking Performance and Demonstration

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REPORT SUMMARY

A new residential and commercial kitchen range utilizing magnetic induction has been developed and tested in the laboratory and in the field to determine the performance and user acceptance of the induction range. This report provides a summary of the laboratory and field tests as well as user comments on the system's performance.

Background
Over $10 billion are spent annually for residential and commercial cooking equipment and the power used to operate this equipment. Commercial restaurant operators are seeking equipment that is faster and more energy efficient, while residential customers want faster, safer, and easier to clean equipment that is very responsive to controls. Developed over the last five years, the Luxine high performance induction range meets these needs and is now ready for widespread commercialization.

Objective
The objective of this report is to demonstrate and validate the performance of the Luxine induction range in both commercial and residential applications.

Approach
The project team performed comparative laboratory tests of gas, standard electric, radiant electric, and induction cooking ranges to quantify the performance of the different ranges under closely-controlled conditions. The Luxine induction range was then field-tested in five residences and seven commercial restaurants, and the users were given a questionnaire to complete regarding their experience with the Luxine induction range, and their perceptions of the unit's future.

Results
In comparative performance tests of several different gas, electric, and induction ranges, the Luxine induction range had the fastest heat-up time, the shortest cool-down time, and the highest cooking efficiency. The Luxine unit had a cooking efficiency of 92%: compared to a cooking efficiency of 72% for the radiant electric range, 47% for the residential gas range, and 30% for the commercial gas range. Field tests conducted with the Luxine induction range showed that users were impressed with the ease of use, control, even heat, and rapid heat-up of the unit. Some concerns were expressed regarding the need to use ferrous cookware with the induction unit.

EPRI Perspective

Based on the laboratory and field tests reported here, the Luxine induction range is ready for wide-scale commercialization with major manufacturing partners. Luxine is now engaged in development efforts with several manufacturers, and the market introduction of the new induction range is expected in the near future.

Keywords

Magnetic induction
Cooking range
Electric ranges
Gas ranges
Cooking performance
Field tests

ABSTRACT

The tests and evaluations of a new induction range both in the laboratory and in field tests, combined with interviews with users of the induction range in residential and commercial kitchens, have provided significant data on the performance and customer appeal of this system. The Luxine induction range has demonstrated substantial improvements in cooking performance, including increased speed of cooking, sensitive low- and high-power control, rapid response to adjustments, and a cool cooking surface. Commercial kitchen field test participants have reported that the Luxine induction ranges increased cooking productivity and helped keep their kitchens cooler. The sensitive low-end power control, combined with smooth power adjustment, enabled commercial chefs to easily melt chocolates, heat milk, and make sauces. Many of these features cannot be duplicated with standard gas or electric cooking.

The induction range has intelligent controls that enable it to shut down when the top plate exceeds pre-set temperature limits, and can be programmed to boil, simmer, and turn off after pre-programmed time intervals. With these features and the positive response from the market survey, the future of induction cooking appears positive. As both commercial and residential users become better acquainted with the benefits of induction cooking, the market for these systems should increase.

In comparative performance tests of a gas range, a radiant electric range, and the Luxine induction range, the induction range had the fastest heat-up time, the shortest cool-down time, and the highest cooking efficiency. The Luxine induction range had a cooking efficiency of 92%, compared to a cooking efficiency of 72% for the radiant electric range, 47% for the residential gas range and 30% for the commercial gas range. Field tests were conducted with five residential ranges and nine commercial ranges, and focused on user acceptance and customer perception of the induction ranges' performance.

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Dongyu Wang

Clifford Jamerson

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1
OBJECTIVES AND BACKGROUND

The objectives of this project are to demonstrate and validate the performance of the Luxine induction cooking range. These objectives will be met by performing the following tests:

- Laboratory tests of gas, radiant electric, and induction cooking ranges to quantify the performance of the different range types under closely-controlled conditions,
- Field tests of the Luxine induction range in five residences and seven commercial restaurants, followed by having the users complete a questionnaire regarding their experience with and perceptions of the Luxine induction range.

It is expected that the information gathered during the laboratory and field tests will provide the background information needed for developing educational and promotional materials related to the operation and marketability of induction ranges.

1.1 History

Over $10 billion are spent annually for commercial and residential cooking equipment and for the power from which they operate. Table 1-1 gives the breakdown on this market.

Table 1-1
Cooking Equipment Market

Market Segment	Market Size
Commercial foodservice equipment supplying 830,000 foodservice units in the U.S.	$10 billion annual sales
Residential cooking equipment: 7.0 million ranges sold annually; Ceramic top range sales have grown to over 2 million units per year and now represent 29% of ranges sold.	$4 billion annual sales

Commercial restaurant operators are seeking equipment that is faster and more energy efficient in order to increase productivity and reduce operating costs. Residential customers need ranges that cook faster, have very responsive controls, and are safe to use and easy to clean. Luxine, Inc. has developed a new generation of high-efficiency induction heating technologies that have fast, smooth power control and that provide superior cooking performance with reduced operating costs when compared to conventional commercial and residential ranges. Luxine was founded as a California corporation in 1994, and imported the first commercial induction ranges into North America. In 1997 Luxine began development of a new generation of

power electronics to produce a more reliable, high performance induction range. Over the last five years, Luxine has been developing this new power electronics system, which was funded in part by the Electric Power Research Institute (EPRI). Luxine's technology has now reached the point of being ready for widespread commercialization.

1.2 The Need

Commercial and residential kitchens need kitchen ranges and other cooking equipment that cooks faster, is more responsive, more reliable, safer to use, and economical to purchase and operate. Restaurant operators are also seeking equipment that is cooler to operate in their kitchens. Induction ranges meet this need by providing fast, safe, and efficient energy transfer to the cooking utensil. Induction ranges are superior performers for countertop and built-in ranges, as well as for display cooking, pasta stations, breakfast bars, and buffet lines. In addition, induction power technology will be used in griddles, fryers, steamers, and other equipment as specifically requested by OEM customers to fulfill their customer's needs for equipment.

1.3 Cooking Platform Options

There are four popular cooking platforms available to the commercial and residential markets. These are:

- Gas
- Electric resistance coil
- Radiant and halogen electric
- Induction

1.3.1 Gas

Gas ranges are available in a variety of configurations. The gas element is available in power outputs rated at 8,500 Btu/hr for small residential ranges to 30,000 Btu/hr per element for larger commercial ranges.

1.3.2 Electric Coil

Electric resistance coil ranges are the oldest traditional electric type of cooking range. Individual coils are rated from 1200 Watts to 2700 Watts.

1.3.3 Radiant Coil

Radiant elements use a resistive wire element, and halogen uses a glass-enclosed light under the ceramic glass-cooking surface. Radiant and halogen cooking elements first heat the ceramic glass top. A pan with a flat bottom is then heated through conduction from the hot ceramic cooking surface. Some infrared energy passes through the ceramic glass to heat the pan.

However, most of the heating occurs by heating the ceramic top and then the pan is heated by conduction. If the pan does not make good contact with the ceramic top, the energy transfer (and therefore the efficiency) of the unit will drop significantly. Because the radiant elements are fixed in size, a pan smaller than the cooking element will draw heat only on the area that is in contact with the heated surface. The heated surface outside of the pan will transfer its heat to the room, heating the kitchen.

1.3.4 Induction

Induction ranges generate a high frequency alternating current magnetic field to heat a pan through a ceramic glass-cooking surface. The changing magnetic field induces eddy currents within the base of the cookware, which is made from a ferrous material. As with a magnet, the energy transfer to the pan is instantaneous and can be easily controllable. Cookware that is somewhat smaller or larger than the induction coil will still draw energy from the cooking range. Because the energy transfer is through the ceramic top, the cooking surface stays cool and the cooking efficiency is very high. Figure 1-1 shows the principle of induction heating.

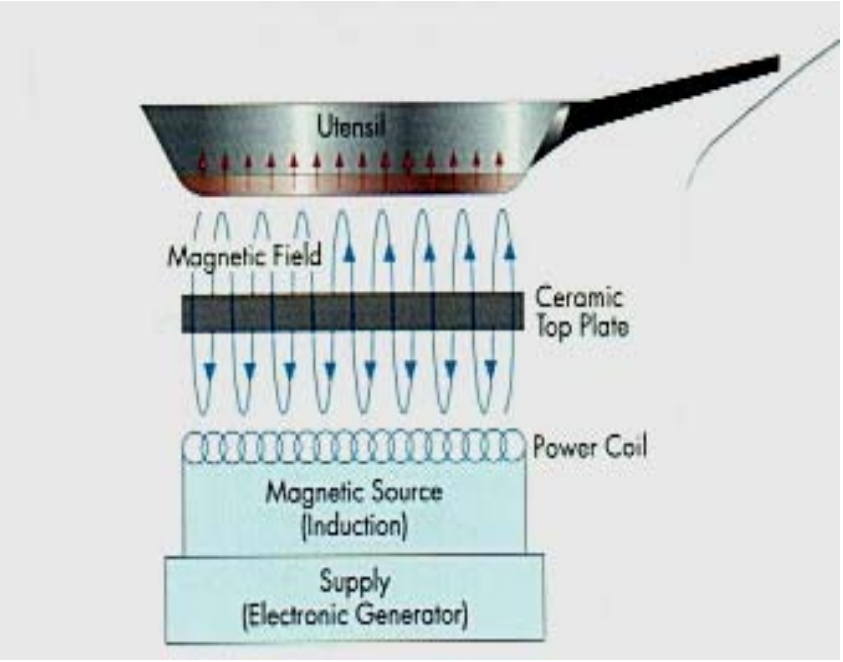

Figure 1-1
Principle of Induction Heating

- Magnetic field generated by Electric power supply passes through ceramic glass top generating heat instantly into the bottom of a ferrous pan.
- The induced eddy currents generate heat.
- Direct energy transfer to the pan is very efficient, fast and responsive.
- Easily controllable
- High efficiency (92%)

2
PERFORMANCE COMPARISONS

The tests and evaluations presented in this report have been conducted according to the ASTM F 1521-96, "Standard Test Method for Performance Testing of Range Tops" from the American Society for Testing and Materials. These tests are used in the foodservice industry to assist in understanding the performance of various range tops and selecting an appropriate system for an installation.

In addition, several new tests have been added which help to identify and reveal the performance advantages of the new induction ranges. Data prepared by the Food Service Technology Center of Pacific Gas & Electric and published in FSTC Report 1022.95.20, "Development and Validation of a Uniform Testing Procedure for Range Tops", which was used for efficiency and production rates for the commercial gas and electric elements and for comparison to the data and tests conducted by Luxine, Inc.

The tests for boiling times, efficiency and production capacity are based on heating a standard amount of water, which was shown to have the same properties as soups and stocks. A 12 inch steel plate was heated in order to determine temperature response and temperature uniformity information. A large assortment of pans was tested to show the affect of the pans with the cooking systems.

2.1 Cooking Performance

2.1.1 Cooking Speed

Cooking speeds were determined by bringing 20 pounds of water from 70°F to 200°F. The upper limit of 200°F was chosen to make it more accurate to determine when water had reached a certain point, since the description of what is a real "boil" for water is difficult to define and measure. Also, actual boiling times and temperatures are functions of altitude above sea level.

The cooking elements compared for this report are:

1. Luxine 3.5 kW induction element
2. Brand A 2.6 kW induction range
3. Brand B 3.5 kW induction range
4. 2.0 kW Radiant Coil

5. 2 kW electric coil element

6. 9500 Btu/hr gas burner*1

7. 20,200 Btu/hr gas burner*2

8. 30,800 Btu/hr gas burner*3

9. 5.1 kW electric coil element

*1,2,3: Efficiency and production rates for the 20,600 Btu/hr burner, the 30,000 Btu/hr burner and the 2.0 kW electric coil were obtained from data presented in the Food Service Technology Center Report 1022.95.20 “Development and Validation of a Uniform Testing Procedure for Range Tops”. The time to heat 20 pounds of water from 70 degrees to 130 degrees was calculated from the production rates.

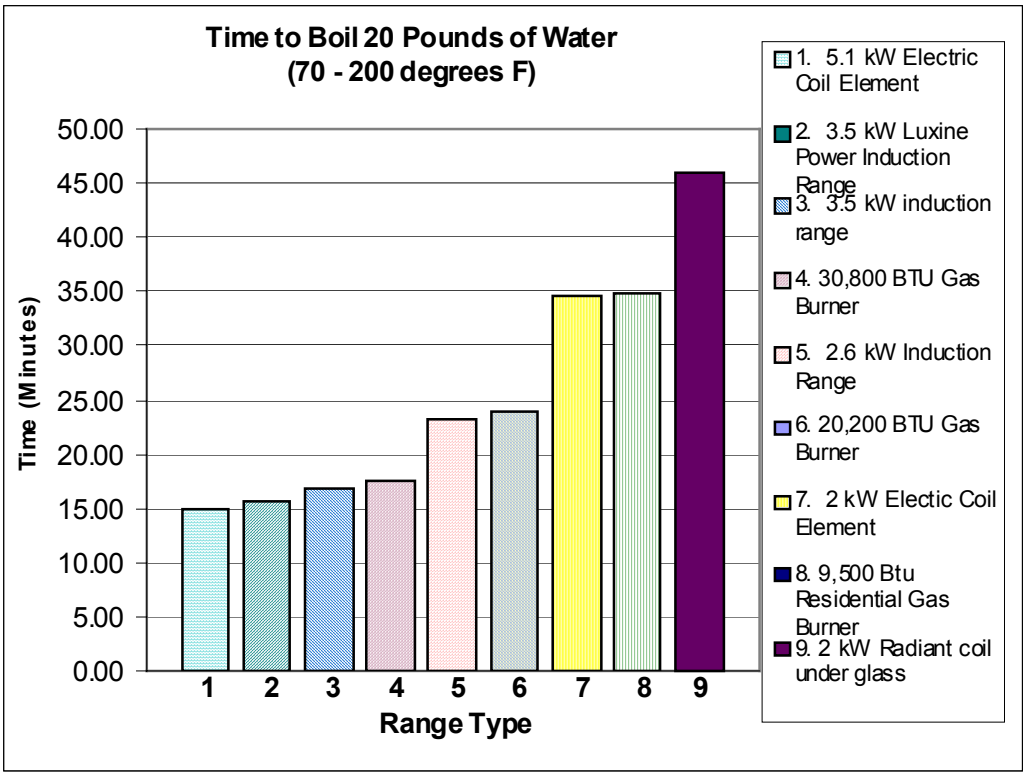

Figure 2-1
Time to Boil 20 Pounds of Water with Different Heating Sources

Figure 2-1 Shows the comparative times to boil 20 pounds of water with the different heating elements.

2.1.2 Production Capacity

Productivity is a key factor in making a restaurant profitable and effective in servicing its customers. As the productivity increases, the restaurant operator is able to serve more customers in a shorter amount of time. The key factors in production capacity that directly affect the production rate are:

1. The basic equipment power

2. The equipment cooking energy efficiency: How much of the input energy is converted to cooking energy.

3. The amount of energy the cooking pan can draw from the power source.

The basic equipment power is the starting point for how much production capacity a piece of equipment may have. However, this is often a misleading number because the actual cooking energy delivered to the food is dependent upon (1) the energy efficiency of the equipment and (2) the amount of power the cooking pan can draw from the power source.

Figure 2-2 shows the total production capacity in pounds per hour for different types of heating elements.

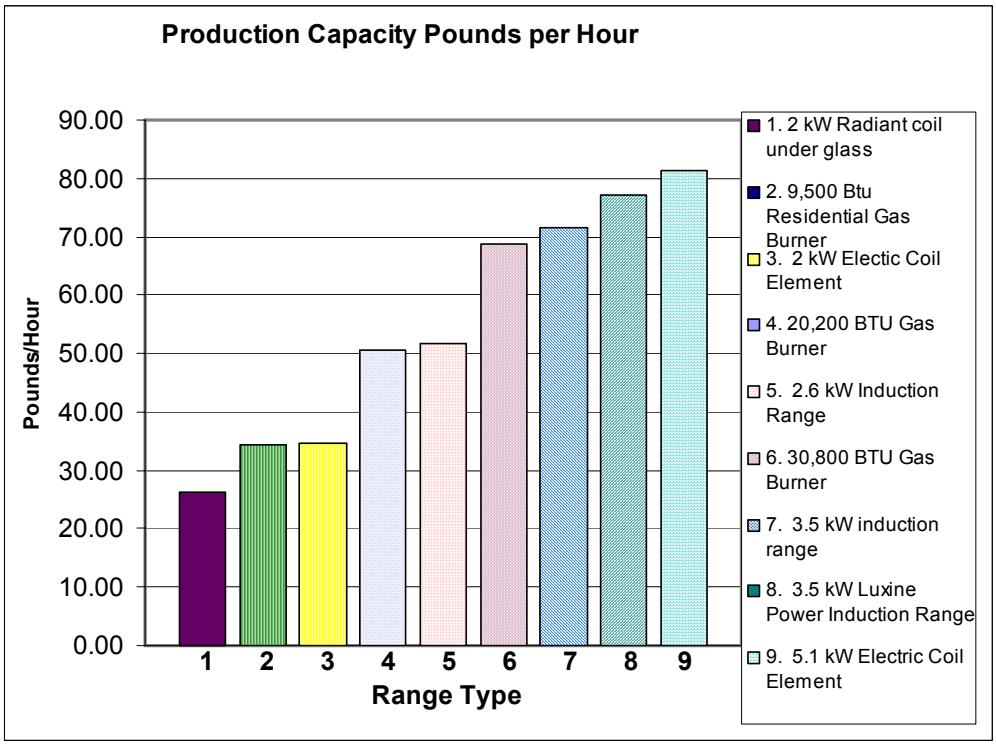

Figure 2-2
Production Capacity in Pounds per Hour

2.1.3 Energy Efficiency

The energy efficiency of cooking ranges has a multitude of effects including the cost of utility bills, air conditioning requirements and associated costs, and the effectiveness and productivity of the cooking range.

The energy that a cooking range delivers to the food is useful energy. The energy that does not go into the food is wasted energy; often radiant energy that heats up the kitchen and consequently requires air conditioning and additional ventilation. This raises operational expenses.

With induction cooking ranges, all the energy goes into the pan through direct energy transfer of electric energy through a magnetic field to the cooking pan. No energy is wasted to heat an electric coil or a ceramic cooking surface. In addition, the induction range only draws power when the pan is on the cooking surface. As soon as the pan is removed, no energy is consumed.

Higher energy efficiency means more energy to the pan, less wasted heat radiated to the kitchen. This means cooler kitchens and less ventilation, which means less noise and expense for commercial kitchens and consumers, as well as less turnover of labor due to a friendlier work environment.

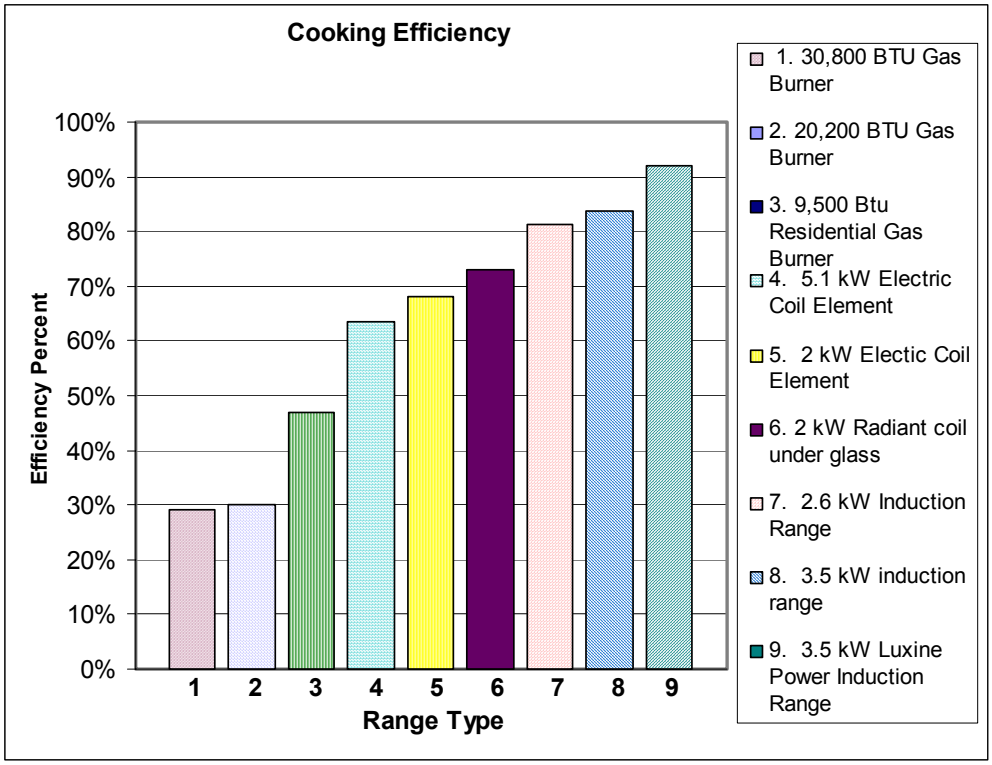

Figure 2-3
Energy Efficiency for Nine Heating Elements

The production capacity is directly related to the energy efficiency of each heating source. Figure 2-4 shows the production capacity per kW-hour of energy input. The rates are normalized in order to show the effect of each unit's efficiency on production capacity.

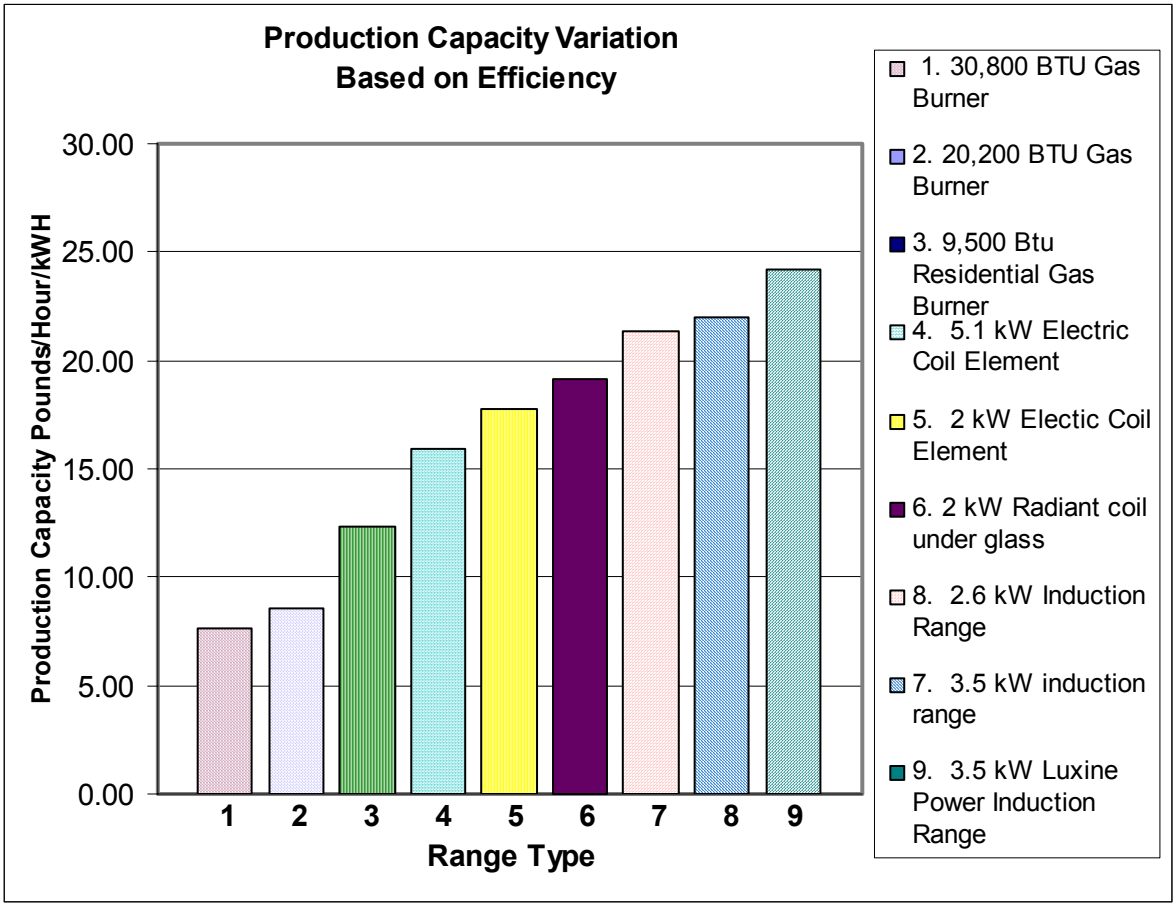

Figure 2-4
Efficiency Effect of Range Type Versus Production Capacity in Pounds/hour/kWh

2.1.4 Temperature Rise

2.1.4.1 Highest Power Output

The speed at which food can be cooked is directly related to the time it takes for the heating elements to heat up the pan. Temperatures are measured and reported as the average of 17 test points on a 12 inch diameter, 1/4-inch thick steel plate placed directly on the top of the ceramic glass or on top of the heating element. Figure 2-5 shows the time required to heat a 12 inch steel disc to 450 degrees F.

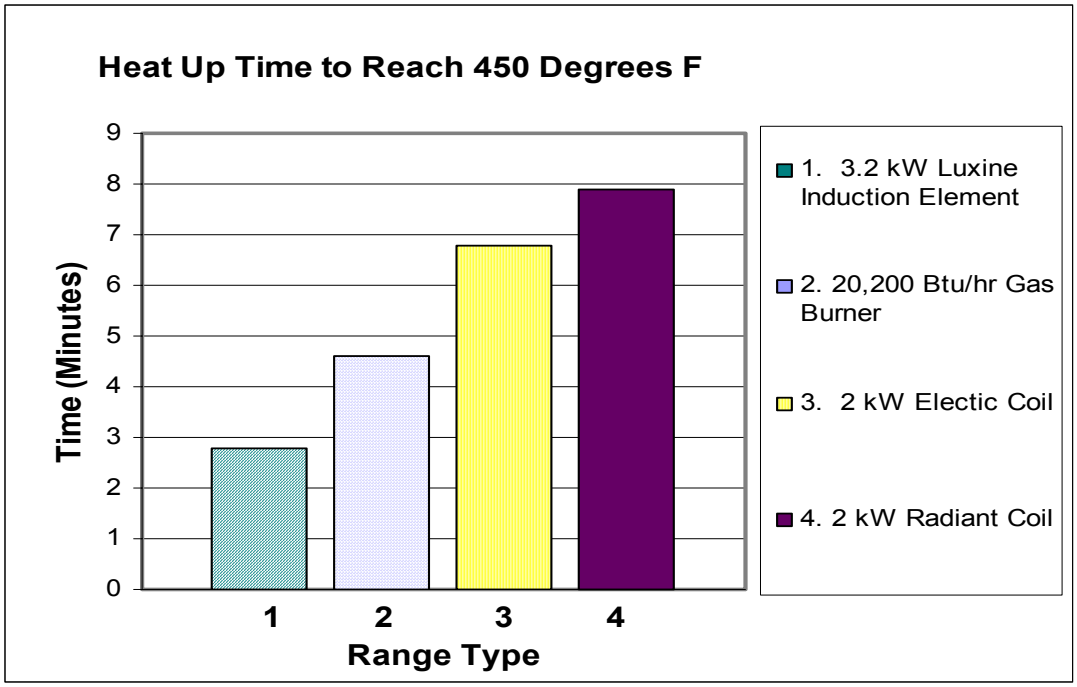

Figure 2-5
Heat Up Time to Reach 450 Degrees F

Figures 2-6 to 2-8 show the comparative times for induction and radiant elements to heat up the steel disc.

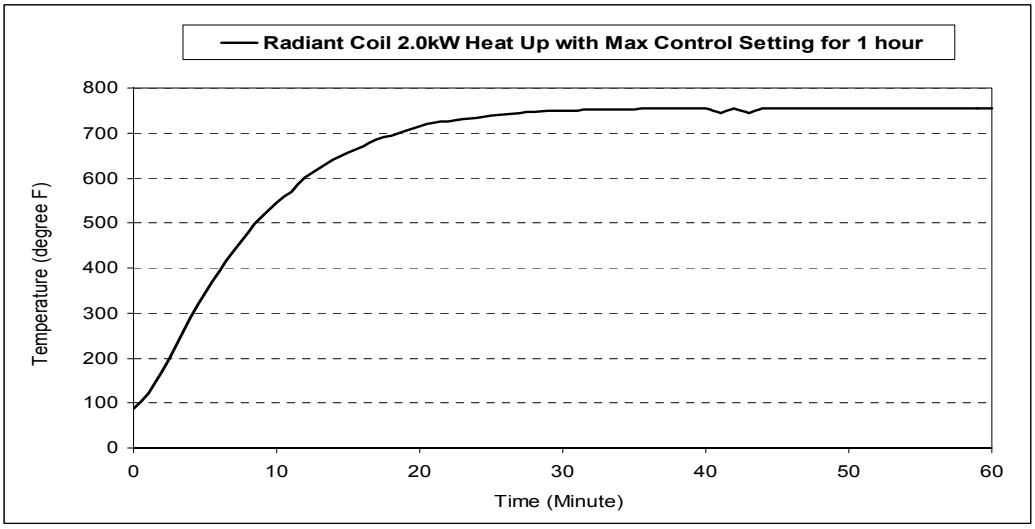

Figure 2-6
Radiant Coil Heat Up of 12" Steel Plate at Highest Power Setting for 1 Hour

Figure 2-6 shows that the 2.0 kW radiant coil has a very precise temperature limit around 750 degrees F, which is to protect the heating elements and glass from over-temperature. The temperature-limiting device turns the power on and off just as an infinite switch does to regulate

the cooking power. The on and off cycling reduces the average energy transferred to the steel plate.

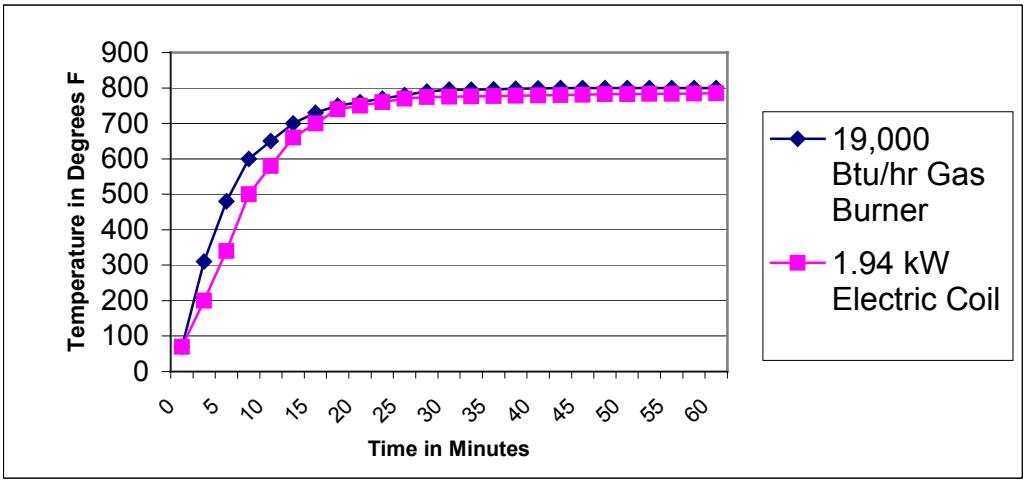

Figure 2-7
Heat Up Temperature for Gas Burner & Electric Coil at Full Power

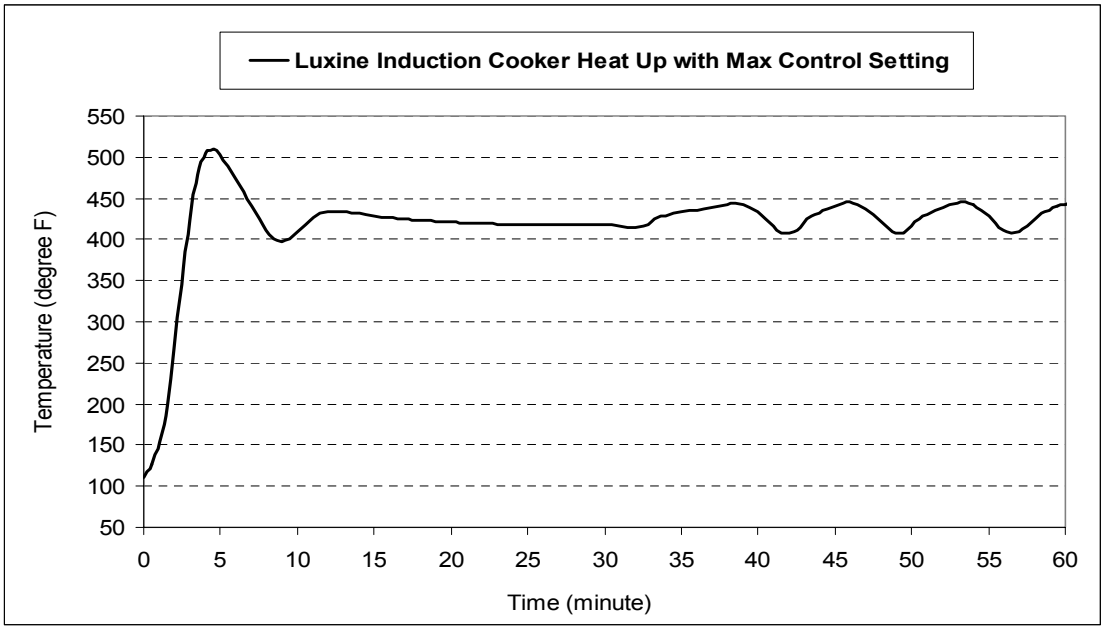

Figure 2-8
Luxine Induction Element Heat Up at Full Power

Figure 2-8 shows the very different control and heating performance of the Luxine Power induction range. Whereas most induction ranges at full power quickly heat up to a maximum temperature of about 400 to 450 degrees F, the Luxine Power induction range quickly heats to nearly 500 degrees F for 5 to 10 minutes and then reduces the power and thereafter regulates the power to maintain high cooking temperature within a safe zone for normal cooking.

The real value of this is in stir-fry and sauté cooking performance. Many induction ranges tested will shut down after 10 to 15 minutes of maximum control setting such as stir-fry and sauté. The Luxine Power ranges allow very high temperature cooking that brings out the tastes and aromas that professional chefs look for. The Luxine induction cooker regulates the temperature at a lower point so that it keeps high temperature cooking and safe thermal limits for the internal electronics.

2.1.4.2 Lowest Power and Temperature Regulation

Low-end power and/or temperature control is a very valuable feature requested by many professional and home chefs. The users of induction ranges want to do a variety of cooking on the ranges that require sensitive low-end power control and temperature control. Some cooking of sauces and chocolates needs very little power over a long period of time.

The advanced Luxine Power™ electronics allows for very low-end control of the range power and easy control for cooking chocolates, sauces and milk products.

Chocolate Melting Test

One test used is to melt a bar of chocolate at the lowest temperature or power setting and record the results over time. A comparative test was done at the Luxine lab with a Brand B 3.5 kW and a Luxine 3.0 kW induction ranges. Power was set at minimum on both units. After about 15 minutes, the chocolate started to harden and dry on the Brand B unit. After 20 minutes the color of the chocolate remained perfect without burning on the Luxine unit. Please see the pictures in Figure 2-9 below.

Figure 2-9
Chocolate Melting and Temperature Regulation Test

The reason for the over temperature and burning is that the Brand B unit is pulsing the output power at about 3.6 kW periodically, and there is a gradual increase in power and temperature to the pan. In contrast, for the low-end power control, the Luxine Power unit is pulsing on and off at only 700W.

The effect of the increasing temperature on low temperature cooking can be shown in the following graph. The graph shows the Brand A and Luxine induction range temperatures at the lowest power setting over a period of one hour.

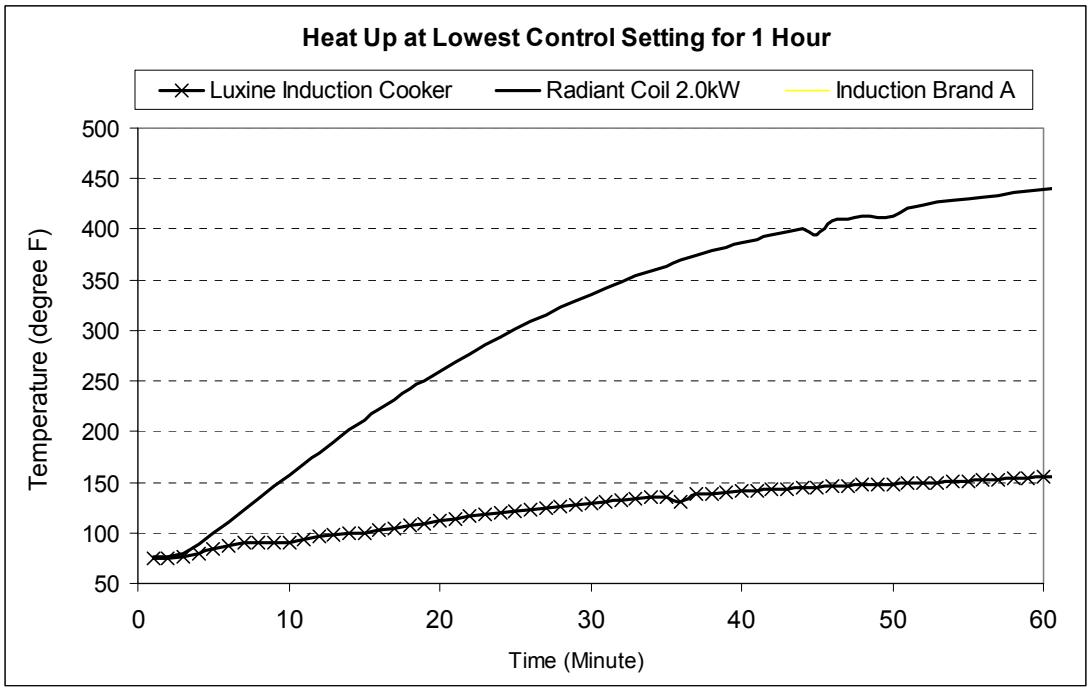

Figure 2-10
Heat Up Temperature Over 1 Hour at Lowest Power Setting

Figure 2-10 shows that after one hour the Luxine induction range at low power reached approximately 150 degrees F. The Brand A induction range reached 321 degrees F and the radiant coil reached 440 degrees F. This means the induction element is able to do special cooking like melting chocolate, making sauces and stocks very well.

For long term heating of delicate sauces, the lower power of the radiant coil and the Brand A induction range would provide too much heat over an increasing period of time.

Appendix C shows the results of gas, electric radiant coils and induction cooking elements for low heating requirements for chocolate, tomato paste and stocks.

For commercial gas ranges and electric coil ranges the heat up curves at the lowest power setting are shown in Figure 2-11.

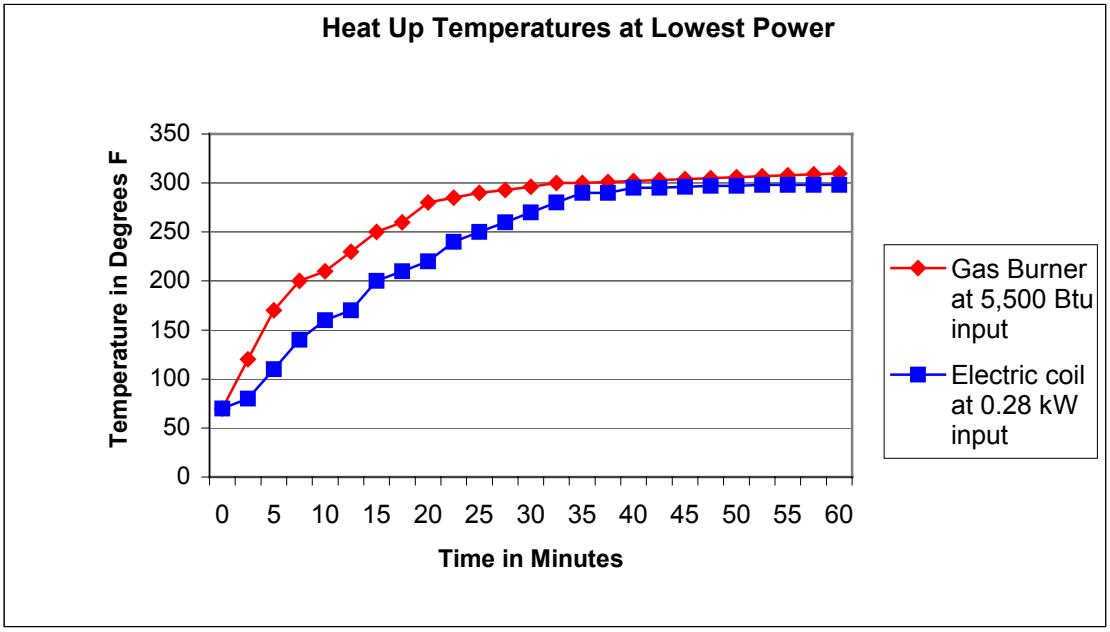

Figure 2-11
Heat Up of Gas and Electric Coil Elements at Lowest Power Settings

The graphs of Figure 2-11 show that over a period of 60 minutes, the commercial gas and electric coil heating elements will increase in temperature to nearly 300 degrees F. This gradual build up of temperature may provide too much heat for delicate sauces, chocolates and other stocks that require consistent low temperatures.

2.1.5 Cool-Down Time

The safety of commercial and residential ranges is very much related to the open flame of gas cooking and the temperature of the cooking surface on electric coils and on ceramic cooking surfaces.

With gas cooking the open flame presents a danger from high heat and also poses a risk of fires and burns. With a gas flame, the sides of the cooking pan and the rim and handle are very hot. Many commercial cooks have wrist burns from touching the rim of a hot pan and holding a handle too close to the pan, which can also cause burns.

With electric coils the coil element gets red hot and then cools slowly. If the pan is not sized to fit the coil and the pan is smaller then the coil, wasted energy is given off and the panhandle can be heated to a point that can cause burns.

With radiant elements under glass, the ceramic glass will turn red hot and then when the power to the element is turned off, the glass will turn dark while the ceramic glass remains dangerously hot. This hot surface will carbonize any spilled food, which then requires a scraper and polish to be removed. As with electric coils, if the pan is smaller than the size of the heating element, the panhandle can be heated and can be dangerous to touch.

With induction heating elements, the ceramic cooking top stays cool around the cooking vessel and the glass under the cooking pan is heated only by conduction from the pan sitting on it. The ceramic glass with induction cooking never gets so hot as to cause instant burns and it will cool much quicker than radiant elements under glass. Because the glass surface is not very hot, spilled foods will not bake onto the cooking surface and they can then be easily wiped up. The bottom of the pan is heated and the handle and rim of the pan stay cool and safe to the touch. This eliminates possible burns from the hot pan rim and touching a very hot panhandle.

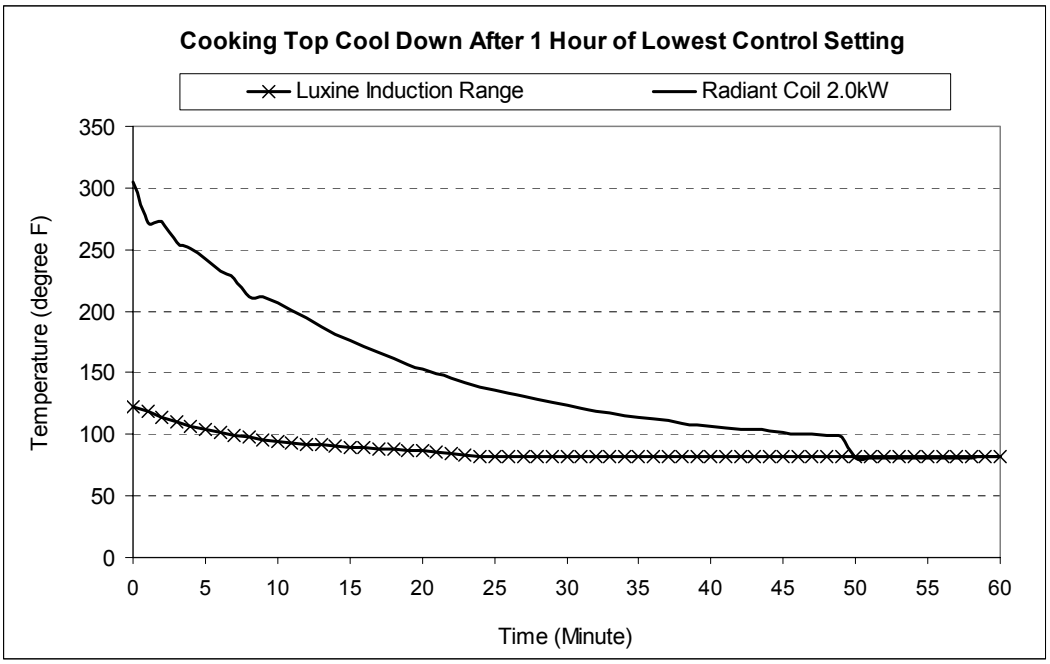

Figure 2-12
Radiant Burner Glass Cool Down After 1 Hour at Lowest Power Setting

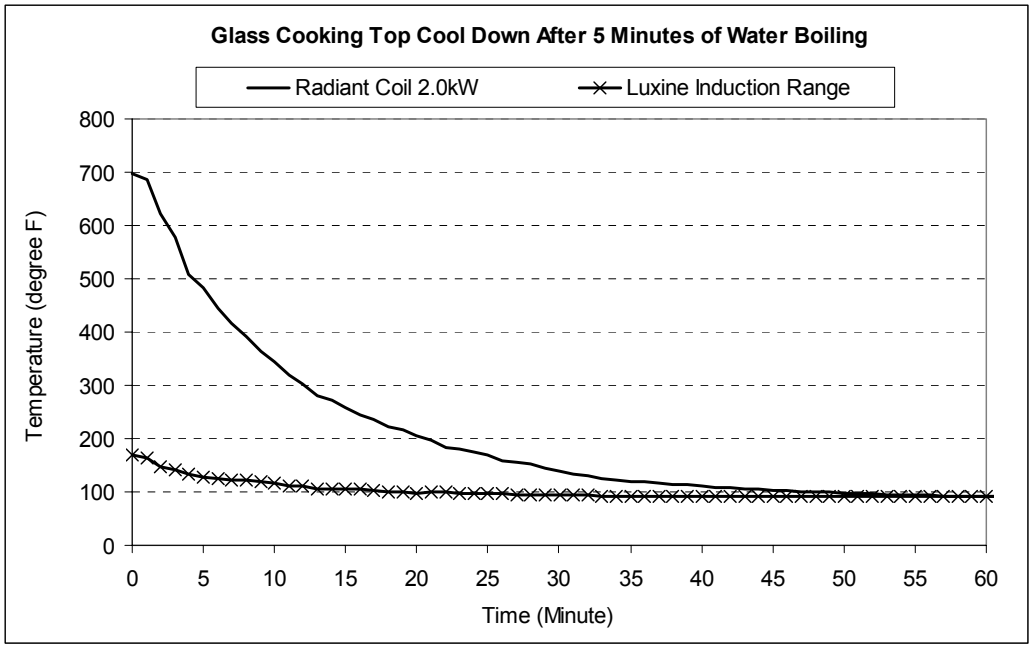

Figure 2-13
Ceramic Top Cool Down After 5 Minutes of Water Boiling

Figure 2-13 shows that the Luxine Power induction range ceramic top was approximately 175 degrees F after boiling water for 5 minutes. The induction range ceramic top cooled down to 130 degrees within 5 minutes.

The induction range top can be touched for a short time even at a temperature of 175 degrees F and would be safe to touch at 130 degrees F. The ceramic top with radiant coils reached a temperature of nearly 700 degrees F after boiling the water for 5 minutes. The radiant element ceramic top took 33 minutes to cool down to 130 degrees and did not cool to less than 175 degrees F for 23 minutes. Consequently, for 23 minutes, the radiant element ceramic top poses a significant safety hazard.

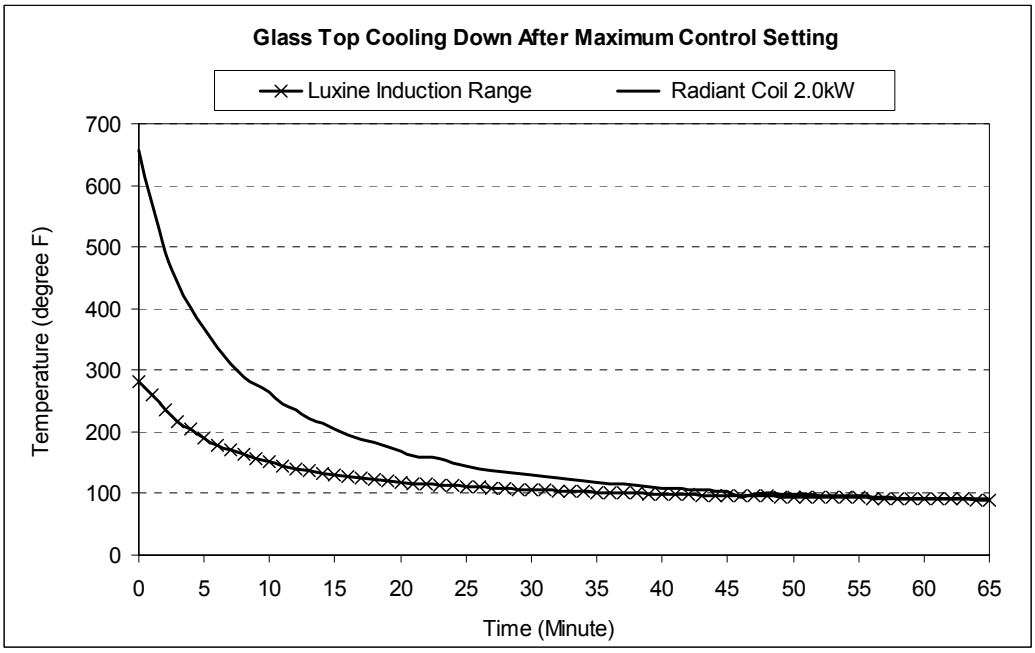

Figure 2-14
Ceramic Glass Cool Down After 1 Hour of High Power Cooking

Figure 2-14 shows that the radiant ceramic top reaches 650 degrees F during high temperature cooking, compared to 290 degrees F for the induction range. It takes the induction range a little over 15 minutes to cool down to 130 degrees F, a point that will not cause any burns. The glass of the radiant burner requires 30 minutes to cool down to the 130 degree F level.

2.1.6 Effect of Cookware Type

The type of cookware has a direct impact on different types of heating elements and in particular on induction heating ranges. Based on different manufacturers' designs, some pans work well with induction electronic systems, drawing 80 to 90 percent of rated power, while others draw only 30 to 40% of rated power. The best ranges will pull the maximum power from all types and sizes of pans.

Most range manufacturers promote and advertise their heating elements based on input power, NOT output power to the food. Consequently, consumers are led to believe that bigger is better (i.e., a 3 kW range is better than a 2 kW range). However, it is not correct to use this rating to determine the overall performance of ranges. As shown in Section 2.1.3, the energy efficiency has a major impact with gas burners utilizing about 30% to 47%, and electric heating elements utilizing less than 75%, of their rated power for cooking.

With the induction range the power rating represents the maximum regulated input power rate at which the induction cooker consumes energy from the AC input power line. UL requires that the maximum power input to a range not be more than 105% (UL197, Section 41.1) or 110% (UL858, Section 51.1) of the marked power rating for residential ranges.

The food service operator cares about the productivity of his equipment, which is directly related to how much energy is supplied to the food through the cookware. Most consumers are led to believe that the best way to determine the productivity is by the power and efficiency of the range. However, the energy supplied to cook the food, and hence the productivity for most induction ranges, is greatly dependent upon the cookware used with the range.

The cookware interacts with the induction range electronics. For the best performance the induction range should utilize nearly full power for all pans used on the range. Luxine has introduced the performance measure unit of High-End Power Uniformity (HEPU) for induction ranges. HEPU represents the output power drawn by a large number of pans of different sizes and ferrous materials.

Luxine has collected and tested as many as 60 different types and sizes of cookware. The following graphs plot the cooking energy drawn by each of them. The cookware is sorted according to the base size. One index number is assigned to each cookware set. As the cookware index changes from 1 to 60, the base size increases from 4.5" to 16". Since the material of the cookware differs significantly, we believe this collection represents a good sampling of the different cookware available on the market for induction cooking ranges.

The maximum cooking power provided by the induction cooker for each cookware set is then plotted. On each figure one line connects all the maximum input power measurements for each cookware set on the same test unit to show the response of different induction ranges to different cookware.

Induction cooking ranges need good magnetic coupling between the cooker and the cookware. Good magnetic coupling needs a proper cookware base material and sufficient cookware base size. However, it is challenging to have good magnetic coupling for all cookware found on the market. So in addition to reliability, safety, and EMC compliance, more power for a broader range of cookware is very critical to the final performance of the induction range.

Most chefs and cooks are used to the power of the heating element heating all pans the same. Since it is beneficial for the induction range to have the same performance feature for the chefs, the induction range should be designed to provide as much power as possible to cookware with less than optimal material and base size. The power consumption for different cooking ranges based on a variety of pans is shown in Section 2.1.7.

2.1.7 Power Consumption

As discussed in the preceding section, the effective cooking power of different brands of induction ranges is dependent upon the cooking pan used with the range. The Luxine induction elements are designed to provide as much power as possible to cookware with less than optimal material and base size. This performance is called constant power or High-End Power Uniformity. With magnetic induction cooking, pans with uneven bottoms or warped bottoms can still be effectively heated.

Figures 2-15 and 2-16 show the effect of different cookware with different induction ranges at 120 VAC and the average power consumption for 60 pans. It is apparent that the cooking power is more predictable, consistent, and less affected by different cookware on Luxine induction ranges, especially for cookware with smaller base sizes, than for other induction ranges. Average power consumption for the four different induction ranges are shown in Figure 2-17. Similar results for operation at 208 VAC are given in Figures 2-18 and 2-19.

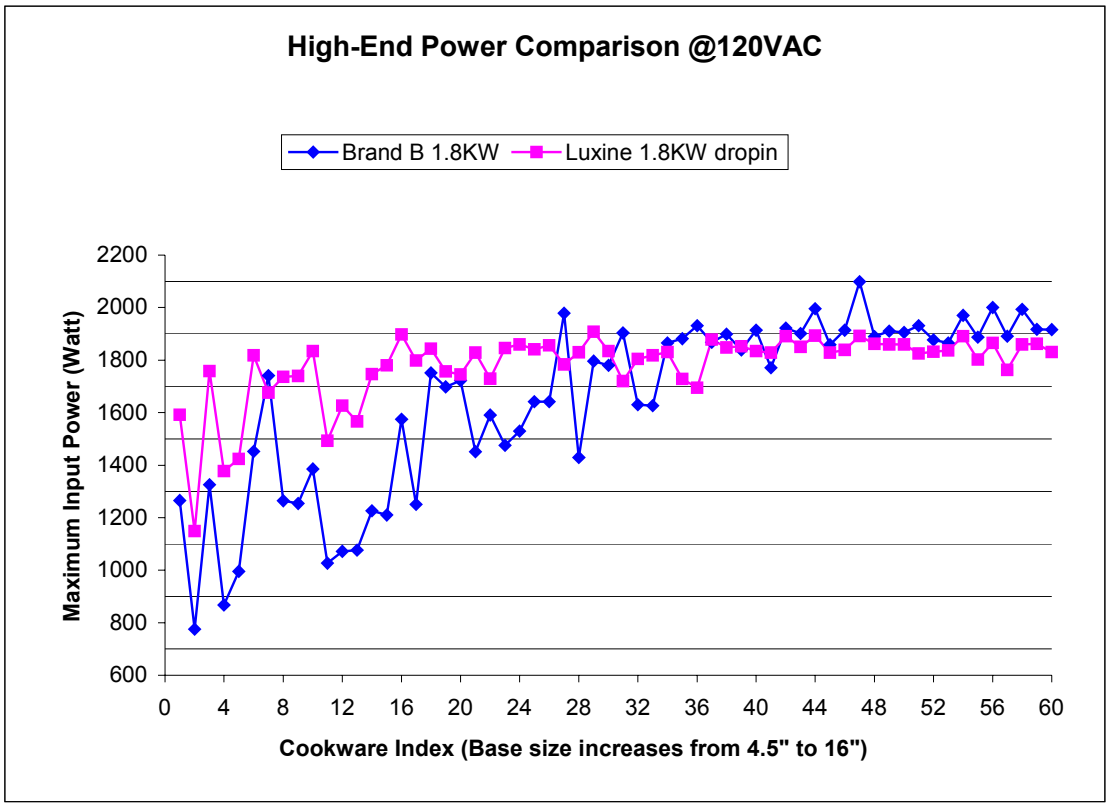

Figure 2-15
High-End Power Comparison for 120-Volt Induction Ranges

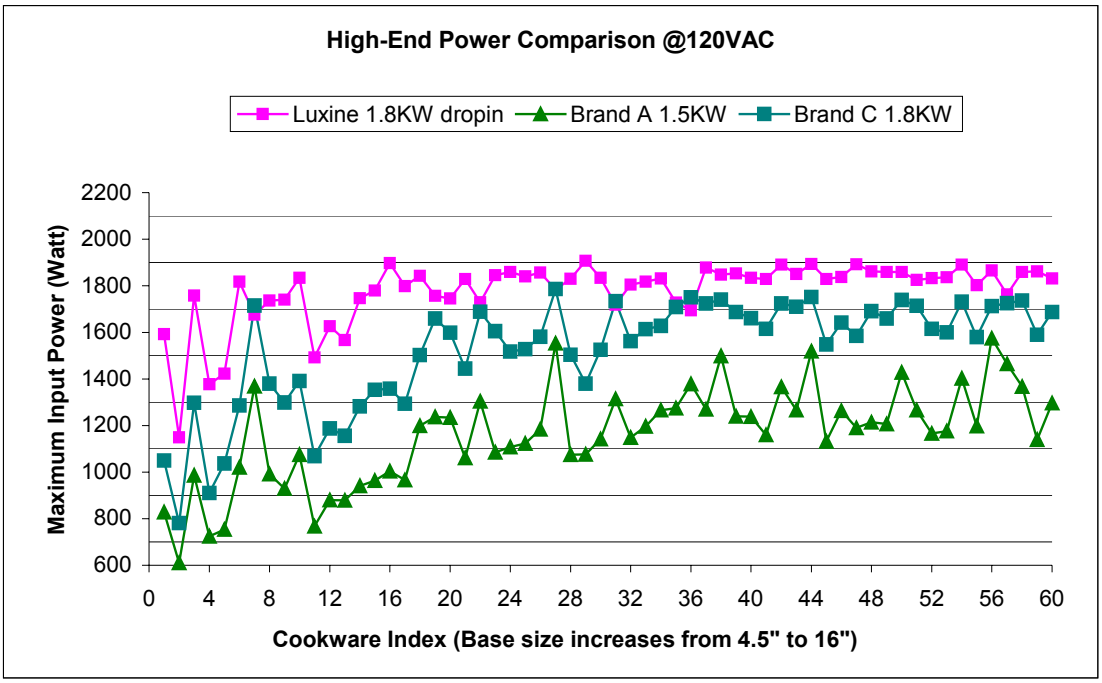

Figure 2-16
High-End Power Comparison for 120-Volt Induction Ranges

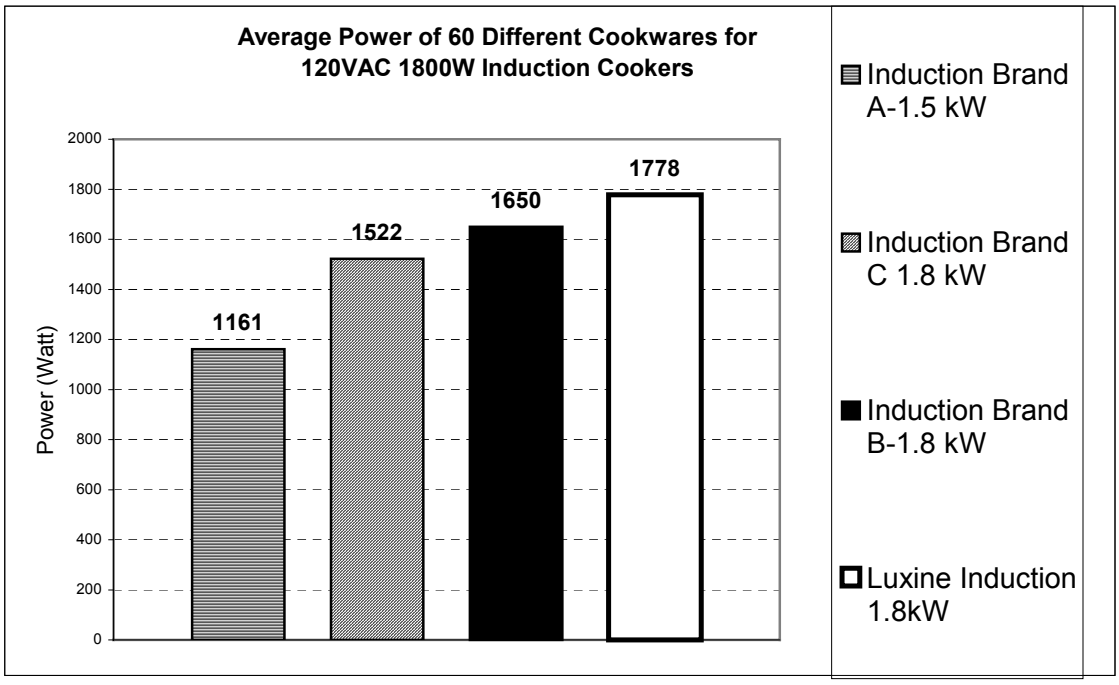

Figure 2-17
Average Power Consumption of 60 Different Cookware Sets for 120VAC Induction Ranges

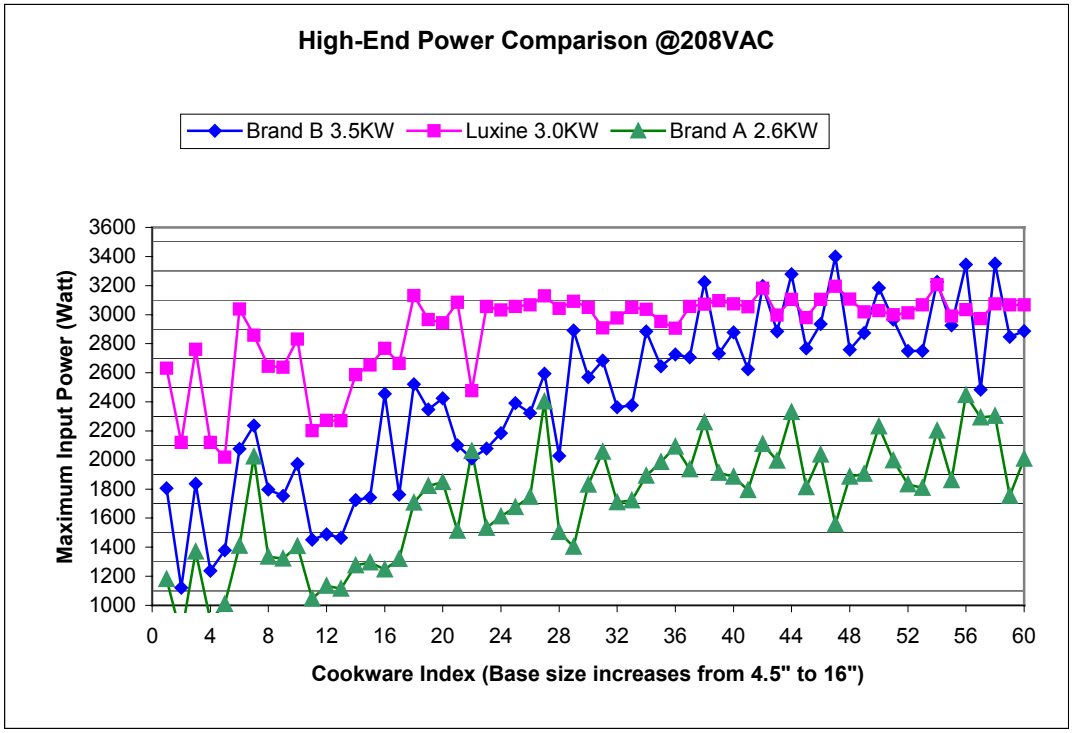

Figure 2-18
Power Output for 208 Volt Induction Ranges

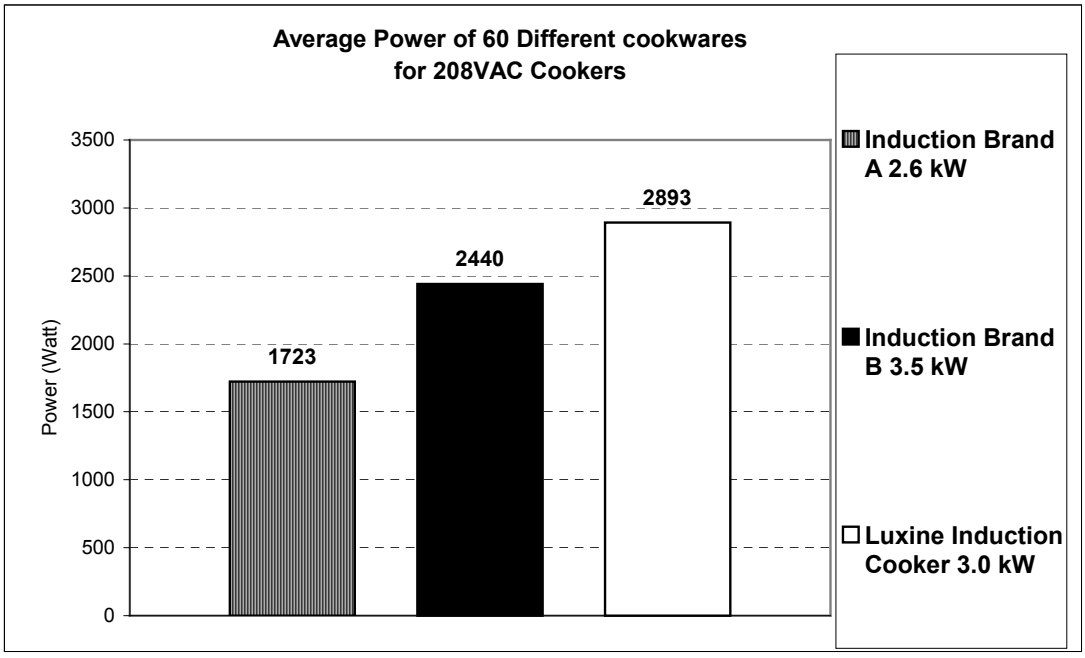

Figure 2-19
Average Power Consumption for 60 Pans on 208 VAC Induction Ranges

The maximum delivered power of Luxine induction cookers is precisely controlled. The high-end power of the 240VAC-3.5KW Brand B units is beyond safe limits as set by UL, and this can be seen from Figure 2-20. Delivering over-rated power is not acceptable because it over-stresses the power supply network, circuit breaker, and cookware. It could also present a danger to the customer by causing fire, electrical shock, or other personal injury as well. The inside electronic components can also be over-stressed and long-term reliability could be adversely affected.

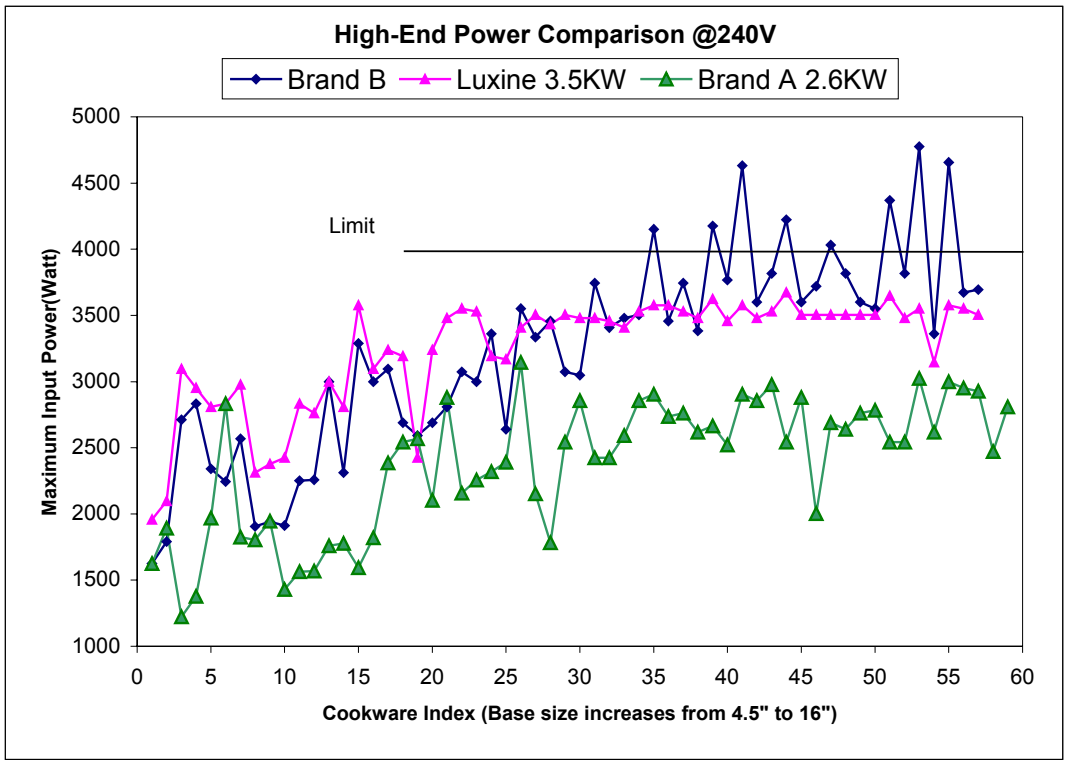

Figure 2-20
Over Limit Induction Range Power Output Comparison at 240 Volts

2.1.8 Responsiveness to Temperature Set-Up

When cooking chocolates, dairy products and delicate sauces, a temperature regulation feature is very beneficial. The induction range provides the capability to set a specific temperature and then regulate the temperature of the pan to the set temperature. For sauces, soups and deep-frying this can be very helpful and is beneficial for both commercial and residential users, making the induction range more useful in the kitchen.

Figure 2-21 shows the cooking temperature control performance of the Luxine induction range. Water is used for testing when the input temperature setup is 220°F. Oil is used for testing when the input temperature setup is 300°F and 400°F. The test pot is a saucepot with an 8.5” diameter flat base.

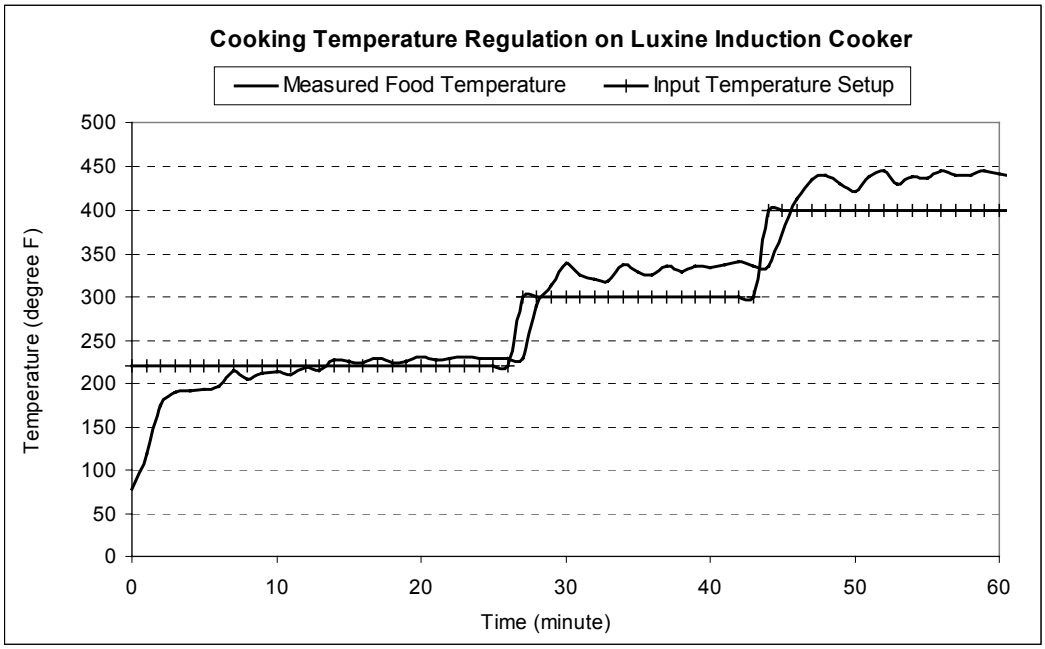

Figure 2-21
Cooking Temperature Regulation of Luxine Induction Element

Figure 2-21 shows that the Luxine temperature control function regulates the temperature within 5% of the 200°F set point and within 10% at temperatures above 300°F. This temperature control is very effective for cooking with regulated temperature controls.

The temperature regulation feature can be combined with the cooking timer control to develop intelligent cooking programs. For commercial or residential use, soups or other foods can be set to cook at a certain temperature for a certain period of time and then turned off.

2.1.9 Temperature Regulation Accuracy for Induction Ranges

Temperature control for induction ranges is accomplished by measuring the temperature under the ceramic top plate. There are a variety of methods to accomplish this, but in all cases the temperature under the glass top estimates the temperature of the food. Consequently, there is a delay and depending on the brand of cooker, there can be large variances in the actual regulated temperature of the food. Over long periods of time, 30 minutes to one hour, the temperature will start to stabilize. On the short term, there will be larger fluctuations in temperature.

The temperature of the ceramic or glass-cooking top can be measured but it does not accurately represent the temperature of the cookware because the physical contact between the cookware base and the cooking top can vary considerably. In addition, the type of pan and the amount of food being cooked has a significant impact on the accuracy of the temperature estimates of the food being cooked. Thus, it is difficult for induction ranges, or other ranges to precisely measure the cookware temperature, not to mention the food temperature.

The following Figure 2-22 shows the variation in temperature regulation from the set point for Brand A induction Range.

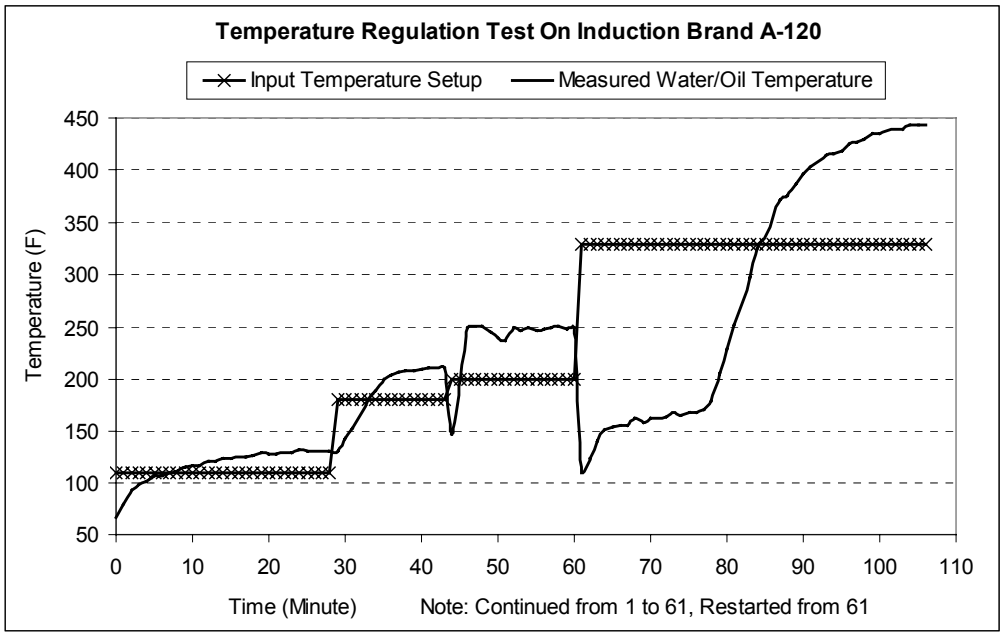

Figure 2-22
Temperature Regulation on Induction Brand A- 120

Figures 2-22 to Figure 2-26 show the temperature regulation in most induction cooking ranges have large fluctuations from the temperature regulation set point.

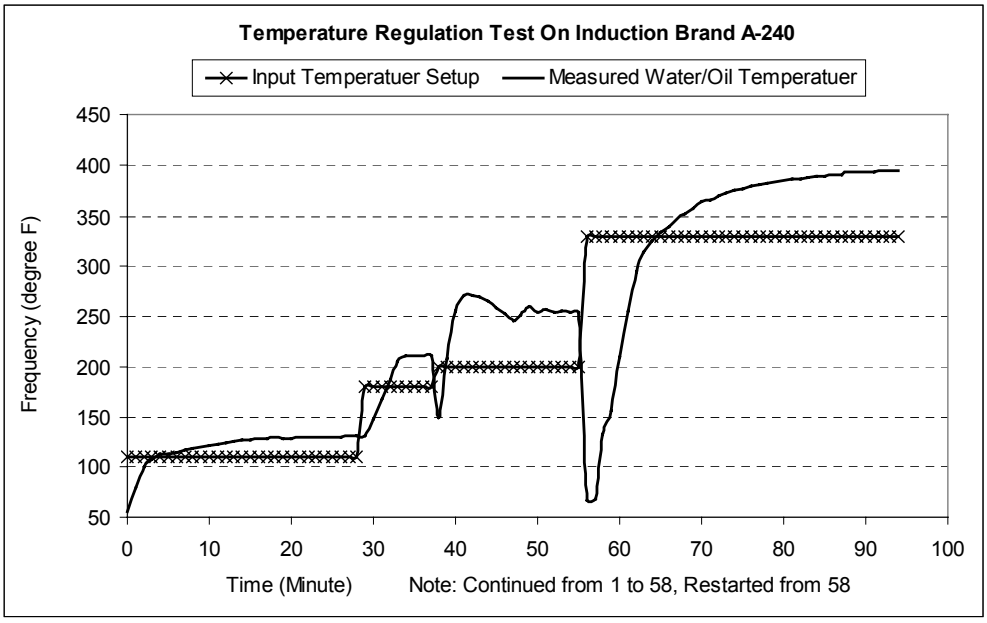

Figure 2-23
Temperature Regulation on Induction Brand A- 240

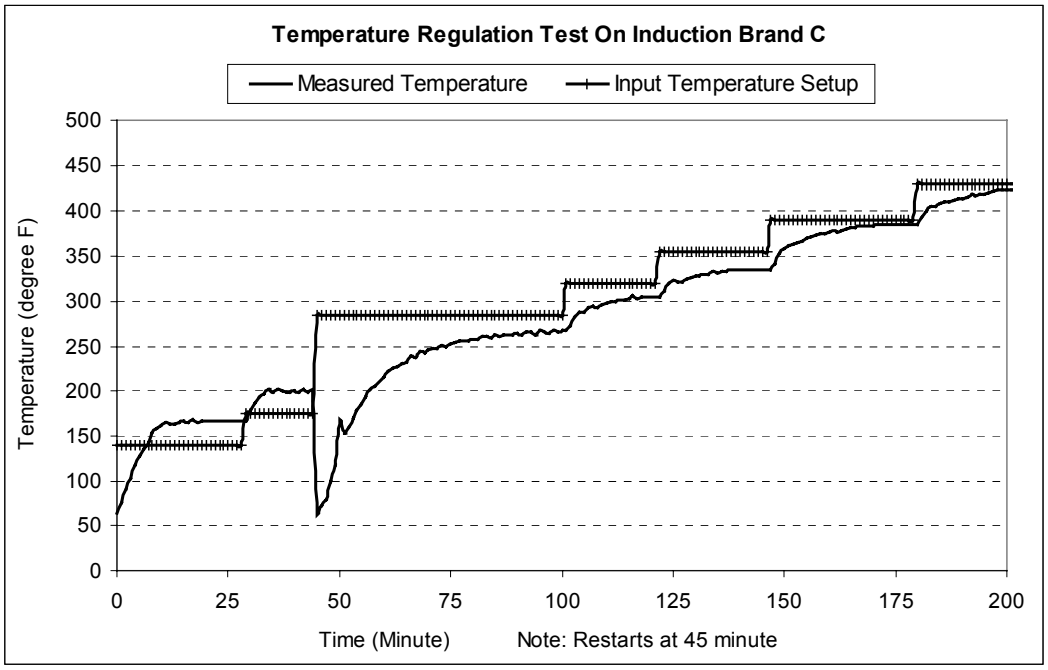

Figure 2-24
Temperature Regulation on Induction Brand C

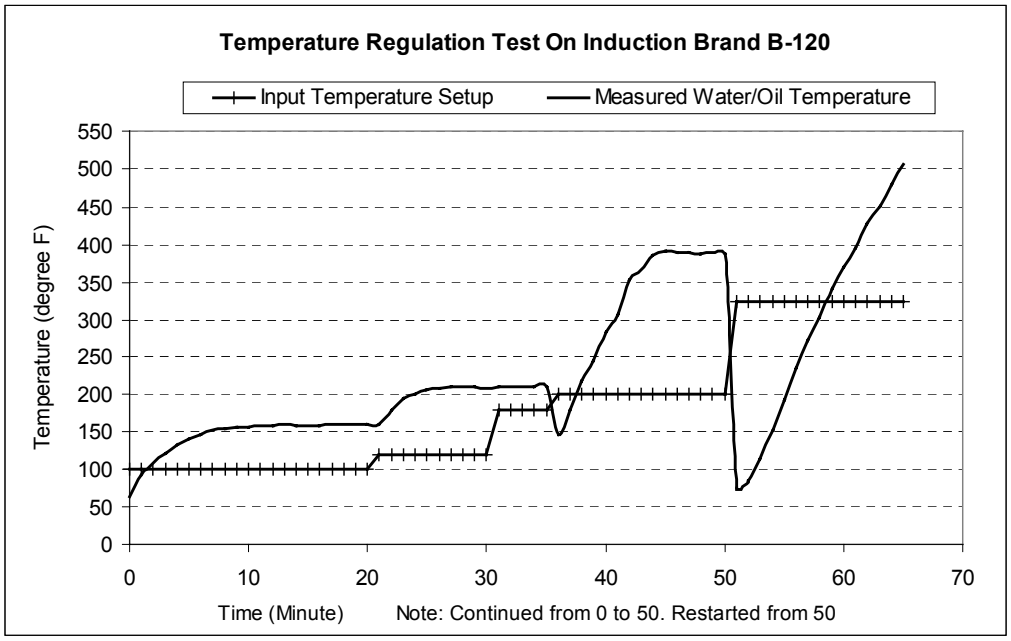

Figure 2-25
Temperature Regulation on Induction Brand B- 120

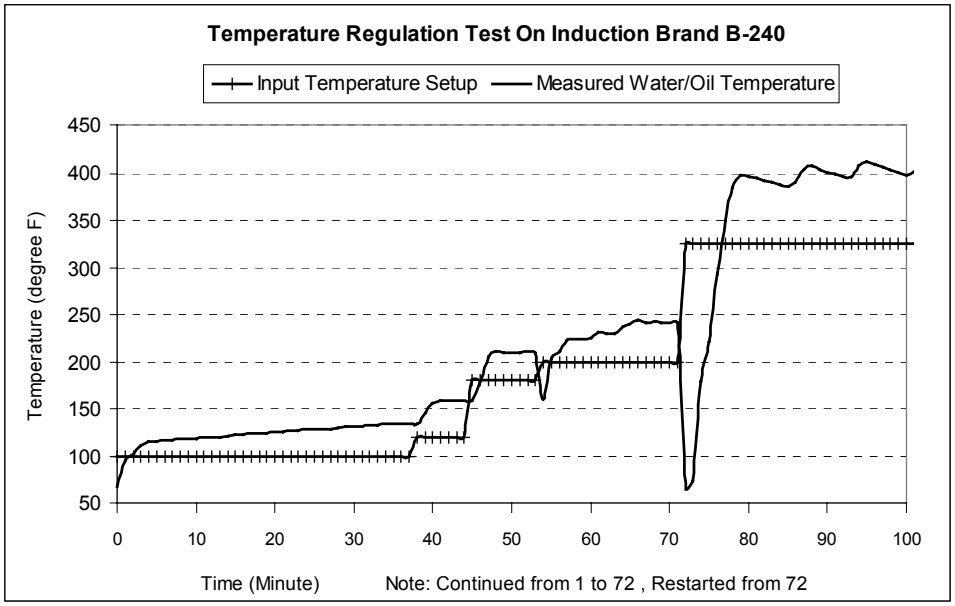

Figure 2-26
Temperature Regulation on Induction Brand B- 240

The temperature regulating systems used in induction ranges although not extremely accurate, have proven useful to foodservice operators in maintaining approximate temperatures for cooking certain foods. It should be noted that there is not a temperature regulating control system available for gas and electric coil and radiant cooking ranges.

An option is to have an expensive external temperature probe as an accessory of the induction range. The temperature probe is then put into the cookware to measure the food temperature. We have received negative feedbacks from chefs regarding this approach. Professional chefs state that they prefer to determine proper cooking via color, smell, and texture of the food.

2.2 Subjective Performance Evaluation

2.2.1 Safety

From our tests above we can conclude that the induction range is a much safer cooking system based on the following:

- The induction range-cooking surface does not get as hot as that of a radiant element smooth top.
- With the induction range, the cooktop is safe to touch within 5 minutes.
- With radiant elements, the smooth-top is very dangerous to touch for the first 15 minutes after it is turned off and is safe to touch after 20 minutes.

2.2.2 Ease of Use

2.2.2.1 Cleaning

The induction range is easy to clean since spilled foods do not stick to the ceramic top. With radiant elements, the top is so hot, that spilled foods crystallize on the surface, often requiring a scraper to remove the burnt-on food and a polish to clean the glass top. With gas and electric coils, the cleanup is considerable and costly to commercial foodservice operators. Gas ranges need to be broken down and the grates and gas nozzles cleaned and then reassembled. Electric coils have open areas that can catch spilled foods and are hard to clean.

2.2.2.2 Responsiveness

Gas and induction ranges have instant response to adjustments in their power controls. Electric resistance and radiant coils rely on conduction to heat the pan and thus the heat-up times and cool-down times are much slower that with gas or induction. The standard electric range is known to be slow in heat-up and when turned off, it maintains a high degree of residual heat. For this reason, professional chefs consider the standard electric range as inferior to gas units, which have instant response of the glass flame.

Because the induction element connects the energy directly to the pan, the heat transfer and responsiveness is faster than with gas. As with any electronic system, the power can be adjusted up and down instantly.

2.2.2.3 Controllability

Most electric coil, radiant and standard induction ranges have 7 to10 steps for regulating the power. The Luxine elements have smooth continuous power just as you would have with the variable flame of gas cooking. The Luxine induction cooker continually regulates power from 700W to 3.5KW with no on and off power pulses. This is a huge advantage for some types of cooking that require continuous high temperature cooking such as sauté or stir-fry cooking. For very low temperature control 700 watts of power is pulsed on and off to provide variable very low temperature control.

2 .2.2.4 Other Features

The induction range also has other features that are valuable to both commercial and residential users. These include:

- The induction range automatically shuts off after a pan is removed.
- The induction range can be programmed to cook for a certain period of time.
- The induction range can regulate the temperature of the cooking appliance.
- The induction range stops drawing any power as soon as the cookware is removed from the surface.

2.2.3 Pans

The induction range requires pans made of a ferrous material on the bottom surface. This is the one drawback often cited regarding induction-cooking ranges. However, more and more pan manufacturers are switching to induction compatible materials. Most pan manufacturers interviewed stated that they can and will make their product pan lines induction compatible, especially as they are seeing a greater demand for such products.

2.2.4 Radiant Heat and Ventilation Requirement

The heat given off by gas ranges and radiant coil elements is very significant and requires extra air conditioning and ventilation systems to keep the kitchen cool. Café Sublime in Florida installed a Luxine induction range and was able to reduce the kitchen temperature by nearly 30 degrees.

3
FIELD TESTS

3.1 Results of Questionnaires, Interviews and Web Site Comments

The field test questionnaires provided valuable feedback on how the induction range is used and the preferences of the users cooking with induction. The following summaries of quotations provide an overview of the reactions of the induction users.

3.1.1 Quotations

- "This is an excellent product." "We have a small restaurant with steady dinner volume. The induction range performs consistently and reliably. Our cooling bills have reduced significantly as has the overall temperature of the kitchen (which used to get miserably HOT with our standard range). We also appreciate the speed of the heat-up on the range. It's gotten us through many crunch times - as well as the speed of cool down." *Executive Chef, Café Sublime.*
- "Extremely good for blanching vegetables as it maintains a hard boil" *Executive Chef, Collins Cafe*
- "I like it for its speed. It takes me 50% less time to make soups" *Executive Chef, Collins Cafe*
- "We had a few problems… with imported units, but it was worth working through them with the results we get" 35.1.1.5 "I find this product somewhat misunderstood by users. It is imperative for any user to learn its functionality. Once the user has been trained the skepticism fades and the product is outstanding to work with." *Executive Chef, Franco Loris*
- "I find the units extremely reliable."
- "The temperature control works well with food that can easily burn."

3.1.2 Summary of Questionnaire Results

- The primary intended uses of the induction cooker are for:
  - Sautee cooking,
  - stir-fry,
  - pasta cooking,
  - omelets,
  - soups and stocks

- The preferred features of the induction ranges ranked by the respondents are:
  - Easy Cleaning
  - Fast Heat Up
  - Cooler Kitchen
  - Sensitive Control of Power
  - Responsive Controls
  - Energy Savings
  - Safety
  - No Open Flame
  - Power
- Respondents favor both a temperature control feature and a timer. Professional Chefs generally rejected both of these features
- Respondents found the high heat good for stir fry and the low heat good for sauces and chocolates.
- Respondents reported great service, good service and in one case "…a few problems with imported units but worth working through them with the results we get"
- Primary concerns of respondents were:
  - Costs of the units
  - Durability
  - Need for compatible pans
  - Even heating
- No respondents cited any health concerns

3.1.3 Positive Comments from Questionnaires and Web Site Searches

- Ease of Use
- User friendly
- Versatility
- Excellent control, just like gas
- Keeps kitchen cool on hot summer days
- Heat is evenly disbursed
- Heat up practically instant
- Do not require pan to be flat

3.1.4 Negative Comments from Questionnaires and Web Site Searches

- Requires ferrous pan: iron, steel, baked enamel steel, magnetic stainless
- Pan manufacturers will develop new lines as market grows.
- Uneven heat on thin pans
- No visible flame for power level indication
- Low power levels on many residential ranges
- Too low of over temperature shutoffs on many induction ranges.
- Serviceability and long-term reliability questions?
- Not enough steps
- Not enough power
- Hot spots - Not even heating
- Can't tell size of cooking coil to match pan
- Thin pans can scorch food from too much fast heat

4
CONCLUSIONS

4.1 Conclusions

Induction heating technology has come a long way from when it first appeared on the market in the 1970's. Reliability and performance have improved considerably. The long-held belief that the induction range needs to work with special pans is fading as more and more pan manufacturers make induction compatible pans available.

The Luxine Power™ electronics allows the maximum power to be delivered to all types and sizes of pans, which in turn provides the fast cooking and consequently, the highest productivity. In summary the benefits are:

4.1.1 Safety

- From our tests above we can conclude that the induction range is a much safer cooking system.
- The induction range cooking surface does not get as hot as that of an radiant element smooth top.
- With the induction range, the cooktop is safe to touch within 5 minutes.
- With radiant elements, the smooth-top is very dangerous to touch for the first 15 minutes after it is turned off and is safe to touch after 20 to 30 minutes.

4.1.2 Usability

- The induction range is easy to clean since spilled foods do not stick to the ceramic top. With radiant elements, the top is so hot, that spilled foods crystallize on the surface, often requiring a scraper to remove the burnt-on food and a polish to clean the glass top.
- The induction range requires pans made of a ferrous material on the bottom surface. More and more pan manufacturers are switching to induction-compatible materials. Most pan manufacturers interviewed stated that they could and would make their product pan lines induction compatible as soon as they saw a demand for such products.

4.1.3 Ambient Heat Reduction

The heat wasted by gas ranges and radiant coil elements is very significant and requires extra air and ventilation systems to keep the kitchen cool. Café Sublime in Florida installed a Luxine induction range and was able to reduce the kitchen temperature by nearly 30 degrees.

4.2 Summary Benefits of the Luxine Power™ Induction Ranges

4.2.1 Improved Performance and Productivity

- Smooth, continuous power output
- Faster heat up times than with gas, electric coil or radiant elements.
- Low-end power control allowing careful cooking of chocolates and sauces.
- Fast: Instant and variable heat control by rotary knob or push button.
- Draws power only when the pan is on the range. No power used when pan is removed.
- Safer, no flame and direct energy transfer to the pan keeps the cooktop cool.
- Fast cool-down of the ceramic top.
- Safer for kitchen workers, the elderly and children.
- Creates cooler kitchens, a better working environment and less labor turnover.

4.2.2 Increased Reliability:

Highly intelligent, high reliability inverter and control system monitors pan size and type, power input and pan temperatures for maximum performance.

4.2.3 Saves Costs:

- Saves energy costs: industry leading 90%-92% efficiency compared to 75% -86% for standard induction ranges, 50%-70% for electric coil and radiant ranges and 35%-47% for gas ranges.
- Saves clean-up costs: smooth top wipes clean and is sanitary.
- Saves ventilation costs and air-conditioning costs: less radiant heat into the air.

Many of the performance and reliability features of the Luxine induction ranges are hidden from the customer. It is important that the overall reliability, performance and of cooking ranges be known to promote the long term reliability, image and benefits of induction ranges. The Luxine Power™ logo is intended to provide a recognizable mark signifying a high standard of performance and reliability that consumers can depend on. The Luxine Power™ logo insures that consumers are receiving optimum performance and operation within UL accepted safety guidelines and that they can expect to receive long life reliability for their induction range.

A
FIELD TEST QUESTIONNAIRE

Field Test Questionnaire

LUXINE, INC.

Please complete the consent form below:

1. Your Name: _____ Title: _____
2. Your primary function: _____
3. Name of your Restaurant_____
4. Address: _____

   City: _____State:_____ Zip: _____

I hereby do _____ or do not _____ consent to have our name and photos of our restaurant operation used in trade journals and magazine publicity articles promoting induction cooking.

Name: _____ Title: _____ Date:_____

5. Do you have gas range _____ or electric ranges _____ in your kitchen?
6. Induction Range Model Number:_____ Voltage Used:_____
7. What cookware and brands are you using on the induction range:

   _____

8. Type of Restaurant: _____
9. Type of foods cooked on the range: _____
10. What do you use the induction range for: Buffet lines _____,

Breakfast bar_____, Omelet station _____ Desert preparation_____

Pasta Station:_____Soups _____ Sauces and Stocks _____

Stock Pots_____ Other _____

11. What meals do you use the range for: Breakfast____Lunch _____Dinner_____

12. Intended usage: Please rank in order of most usage 1-10:

    a. Sautee _____
    b. Stir fry _____
    c. Omelets _____
    d. Frying _____
    e. Soups _____
    f. Stocks _____
    g. Heating Pasta _____
    h. Chocolate & Deserts _____
    i. Other _____

13. Do you use mostly Gas_____ or Electric _____

14. What power is available for induction range?
    120 Volt____208/240V single phase_____ 208 volt 3 phase_____

15. What are the features you like best about induction? Please rank 1 to 11 - 11highest.

    a. Energy savings _____
    b. Sensitive control of power _____
    c. Fast heat up _____
    d. Responsive controls - controllability _____
    e. Easy Cleaning _____
    f. Safety _____
    g. No open flame _____
    h. Power _____
    i. Cooler kitchen _____
    j. Digital readouts _____
    j. Portability _____

14. What type of units would you like to have in your restaurant?

    Counter top_____, Drop in _____ Full Range with oven _____

    Full range with refrigerated base _____

    Portable carts _____ Other _____

15. Is there enough power for your use?_____ Is there too much power_____?

16. Do you use the high heat?_____ Does the range get hot enough for stir fry
17.

18. Do you use the high heat?_____ Does the range get hot enough for stir fry

    and sauté?_____?

19. Would you like to have a temperature control function?_____

    a. For what purpose?_____

20. Does the range get hot enough for stir fry and sautee

21. Does the range get low enough for chocolate and milk and sauces
22. how many ranges do you use
23. What commercial ranges do you use.
24. would you consider using an induction range for the back of the house cooking?
25. What controls do you prefer? Rotary knob _____ Push button_____

26. Would you like a timer? _____

27. Would you like a temperature control feature _____

28. Please check necessary features:

    a. ON/OFF
    b. Power Indicator digital readout _____ or row of LED lights _____

    c. Temperature Indicator _____

    d. Thermostat control _____

    e. Cooking Timer _____

29. Is the display easy to understand and use: Please comment:

    a. _____

30. Do you like the range for its:
    a. Speed _____
    b. Responsive ness _____
    c. Easy cleaning _____
    d. Portability = move from area to area: _____

31. How is the reliability _____

32. Have you had any service problems _____

33. What changes and improvements would you like to see?_____

_____

34. What are your concerns:

a. Cost _____
b. Need more testing _____
c. Need compatible pans _____
d. Durability _____
e. Health concerns? _____
f. Easy maintenance _____
g. Even heating _____

35. Other comments:

_____

_____

B
BOILING TESTS

Boiling Tests

A water boiling test was done by a restaurant chain in Quebec City. Times taken for the three 3.5kW induction cookers to boil 18 liters of water from 4°C are listed below. Luxine branded induction cooker is 11 minutes faster than Brand B unit and 5 minutes slower than Brand D unit.

Table B-1
Water Boiling Test

Induction Cooker Brand	Time to Boil (minutes)
Brand D 3.5 kW	29
Luxine 3.0 kW	34
Brand B 3.5 kW	45

C
INDUCTION TEST #2

Induction Test #2 (9/6/00)

Conditions - Watts remained the same as before. Simmer control was changed in order to reach low setting without element cycling on at high

1. **TEST** - Melt and hold 2 squares of baking chocolate on lowest setting in heavy skillet without lid for one hour; no stirring.

   RESULTS - Chocolate slid from bottom when tilted - no sticking

2. **TEST** - Cream of Tomato Soup
   Mix well in medium saucepan 1 (10 3/4 oz) can of condensed tomato soup and 1 can of milk. Cover and heat on low setting without stirring. Check every 10 minutes and record results. Continue checking for 1 hour.

   RESULTS - Induction - setting 2

   15 min. - holding very low simmer
   30 min. - good steady simmer
   45 min. - maintaining simmer
   1 hour - poured soup from pan - no sticking noted after simmering 1 hour.

3. **TEST** - Clarifying butter - place 3 sticks of whole butter in 2-quart saucepan. Simmer until the fat separates from the milk solids.

   RESULTS - Induction - setting 1

   10 minutes - butter 75% melted
   30 minutes - butter completely melted but not simmering increased setting to 2
   45 minutes - butter clarified

4. **TEST** - Place 1 cup water, 1/2-cup rice, 1-tablespoon margarine, and 1-teaspoon salt in medium saucepan. Cover and bring to boil. Reduce heat, simmer 15 minutes. Record results

   RESULTS- Induction - setting 1 no sticking - rice light and fluffy

5. **TEST** - Country Fried Steaks in Gravy

Seasoned cube steaks dipped in egg, dredged in flour, browned on each side in 1/3 cup hot oil. Remove steaks and make gravy with remaining hot oil, 1 tablespoon flour, 2 cups water, seasonings. Return steaks to gravy, simmer in covered skillet for one hour with no stirring.

RESULTS - Induction - setting 1 very light sticking on bottom due to flour - no burning of flour noted after simmering for 1 hour.

6. **TEST** - In 6 qt stockpot, browned 2 lbs. stew meat. Add 4 its. water and seasoning. Cooked over medium heat for 30 minutes. Add fresh potatoes, carrots, onions, seasonings, and additional beef stock. Let simmer for 4 hours.

   RESULTS - Poured beef stew into another pot. There was no sticking or burning noted inside the stockpot after simmering for 4 hours.

D
TEST SITES

Test Sites

Commercial Installations:

1. Ritz Carlton
2. Renaissance Hotel
3. The Inn at Washington Hotel & Restaurant
4. Johnson & Wales University
5. Collins Cafe
6. Café Sublime
7. Bravo Pizza

Residential:

1. Family
2. Family
3. Family
4. Family
5. Family

E
LUXINE INDUCTION RANGE

Figure E-1
Luxine Induction Range

Program:
Commercial Markets

About EPRI

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

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