

**Development and Validation
of a Standard Test Method
for Rapid Cook Ovens**

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PREFACE

The decisions involving the purchase of modern food service equipment are influenced by many factors. Cost is certainly a priority. Are extra features worth the extra cost? Performance considerations are crucial. Will advanced technology, fuel-efficient appliances show a good return on the investment? Should appliances be gas or electric? How much will they cost to operate? Can an appliance meet peak production demands? The food service industry has historically relied on manufacturer specifications and limited test data when selecting new equipment.

Dedicated to the advancement of the food service industry, the Food Service Technology Center (FSTC) has focused on the development of standard test methods for commercial food service equipment since 1987. The primary component of the FSTC is a 10,000 square-foot appliance laboratory equipped with energy monitoring and data acquisition hardware, 60 linear feet of canopy exhaust hoods integrated with utility distribution systems, appliance setup and storage areas, and a state-of-the-art demonstration and training facility.

With support from the Electric Power Research Institute (EPRI), the Gas Technology Institute (GTI), and the National Restaurant Association, and under the direction of the FSTC Advisory Group, the research team develops standard test methods to evaluate the overall performance of gas and electric cooking equipment. These test methods focus on measuring the energy consumption and production capacity of an appliance as it is used to cook standardized loads of typical food product.

After the research team has developed a test procedure for a particular appliance category, the document is submitted to The American Society for Testing and Materials' (ASTM) Subcommittee F26.06 on Productivity and Energy Protocols, part of the F-26 Committee on Food Service Equipment. Once balloted and approved by the main F-26 Committee, the test procedure is jointly submitted to ASTM and the American National Standards Institute (ANSI) for society level ballot and published as an official ASTM standard test method.

Rapid cook ovens, a relatively recent addition to food service industry, have been carving out a niche in today's fast-paced culinary world. With the food service industry expanding to advance the "on-the-go" market segment, equipment manufacturers are designing appliances to meet the needs of time-conscious operators and consumers. The market opportunities for these high performance ovens opened the door to using new and innovative technologies and there is strong interest in the relative merits and performance of each of these cooking systems.

EXECUTIVE SUMMARY

Rapid cook ovens have been available only a few years, but in that time, they have become increasingly popular in the food service industry because of the desire to prepare high quality food in the shortest possible time. These ovens employ a variety of heat transfer technologies to achieve the shortest possible cook times but in all cases, the manufacturers place a high priority on food quality. Because of the different approaches each manufacturer has chosen in designing their rapid cook ovens, these ovens have different performance and energy consumption characteristics. Under the technical direction of a National Advisory Group comprised of individuals from gas and electric research entities as well as various end-user organizations, the Food Service Technology Center (FSTC) developed a draft test method for evaluating and comparing the performance of rapid cook ovens.

Researchers resolved a variety of complex issues during this investigation. The first of which was deciding on a set of performance parameters that would accurately describe rapid cook oven energy usage. The researchers had to take into account the technical and operational diversity of the rapid cook ovens, including the fact that some of these ovens require a preheat period and consume energy when idling, while others do not. Another aspect of these ovens that had to be accounted for is how their control systems differ from traditional ovens. Rapid cook ovens are not controlled based on the temperature in the oven cavity and there is no standard temperature for cooking a particular food product. Instead, the rapid cook ovens utilize a precisely timed cook cycle and vary the internal temperature as necessary to deliver just the right amount of heat to the food product. Because rapid cook ovens do not preheat to a specific oven cavity temperature, the test method specifies that preheat is complete when the oven has reached a ready-to-cook state. Likewise, the idle energy consumption is measured while the oven maintains this ready-to-cook state, which is independent of the oven cavity temperature.

Another technical challenge was developing a repeatable cooking test for measuring cooking-energy efficiency and production capacity. This involved choosing a representative food product, establishing an acceptable endpoint that would ensure that similar appliances performed the same amount of work during the test, and developing equations for calculating the rapid cook oven cooking-energy efficiency. The researchers chose pizza and chicken breasts as the two test foods because they are typical foods that would be cooked in a rapid cook oven and because these two food products had been used successfully in the deck, conveyor, and combination oven test methods. The researchers were also able to successfully utilize the endpoint temperature measurement techniques from these previous test methods.

Since the energy required to cook a food load in a rapid cook oven is not driven by the thermostat but is instead determined by the cooking program that is chosen, light and medium sized food loads do not require significantly less energy than a heavy load. However, when a rapid cook oven is used to barrel-cook one food load after another, the energy required to cook each individual load will decline for the first several loads before stabilizing. Because of these unique operating characteristics, the rapid cook oven test method differs from the conveyor, deck, and combination oven test methods, as it does not include a light or medium load food test. Instead, the rapid cook oven test method includes a single run test for each of the two food products, chicken breasts and pizza, and a barreling test for pizza. The researchers determined, during sensitivity testing, that the results for the barreling tests using either chicken or pizza were the same and therefore were able to remove the barreling test for chicken from the final test method.

The draft test method was applied to two different rapid cook ovens at the FSTC. Rapid cook oven A was a 10.8 kW electric oven utilizing a combination microwave/convection heat transfer technology. Rapid cook oven B was an 11.9 kW electric oven that used a quartz-halogen-lamp heat transfer technology. The application of the test method to two different rapid cook ovens yielded distinct and unique test results for each appliance. These results highlighted differences in performance between the two rapid cook ovens, which may be explained by differences in appliance design—thus confirming the value of the test method. Table ES-1 summarizes the test results for these two rapid cook ovens.

Facility designers and equipment specifiers can use the unbiased performance data generated by the rapid cook oven standard test method as an important tool for choosing the right rapid cook oven for a given end use. The standard test method also provides benchmark data so that improved designs can be effectively documented and designers and manufacturers can show value and be rewarded for their innovations. Since rapid cook ovens represent a new category of appliances, the standard test method also has the potential to help accelerate innovation. By applying the test method to rapid cook oven prototypes, the performance data that is generated can help shape the design of new products in addition to documenting the performance of existing products. As the market for, and availability of rapid cook ovens expands, the FSTC will expand the database on rapid cook oven performance and continue to document this information in published FSTC research reports.

**Table ES-1.
Summary of Test Results.**

	Rapid Cook Oven A		Rapid Cook Oven B	
Heat transfer technology	Microwave/convection		Quartz halogen lamps	
Rated Input (kW)	10.8		11.9	
Measured Input Rate	10.8		11.4	
Preheat and Idle Tests:				
Time to ready-to-cook (min)	24.0		0.0	
Preheat Energy (kWh)	2.48		0.0	
Idle Energy Rate (kW)	0.98		0.0	
Single Run Pizza Test:				
Load Size (pizza/Load)	1		1	
Cook Time (min)	1.2		2.5	
Production Capacity (lb/h)	57.1		31.0	
Production Capacity (pizza/h)	39.6		21.7	
Cooking Energy Rate (kW)	9.0		7.2	
Cooking-Energy Efficiency (%)	32.2 ± 0.4		17.7 ± 0.7	
Single Run Chicken Test:				
Load Size (Chickens/Load)	6 each on pressware plate		5 each on pyroceram dish	
Cook Time (min)	1.6		4.5	
Production Capacity (lb/h)	44.3		18.0	
Product Shrinkage (%)	22.0		19.5	
Cooking Energy Rate (kW)	10.6		11.1	
Cooking-Energy Efficiency (%)	31.4 ± 1.0 ^a		20.0 ± 0.9 ^a	
Barreling Tests:				
	Cooking Energy Rate (kW)		Cooking Energy Rate (kW)	
Food Load Number	Pizza	Chicken breasts	Pizza	Chicken breasts
<i>Load #1</i>	9.0	10.6	7.2	11.2
<i>Load #2</i>	9.0	9.9	7.2	9.6
<i>Load #3</i>	8.0	9.9	5.8	9.1
<i>Load #4</i>	8.0	8.4	5.8	9.1
<i>Load #5</i>	7.0	8.4	5.3	8.8
<i>Load #6</i>	7.0	8.4	4.8	8.8
Total energy rate reduction (kW)	2.0	2.2	2.4	2.4

^a This range indicates the experimental uncertainty in the test result based on a minimum of three test runs.

INTRODUCTION

BACKGROUND

Rapid cook ovens have been available only a few years, but in that time, they have become increasingly popular in the food service industry because of the desire to prepare high quality food in the shortest possible time. These ovens employ a variety of heat transfer technologies including microwave, quartz halogen, and high-velocity or impingement convection to achieve the shortest possible cook times. Often, one or more of these technologies are combined within the oven. For example manufacturers have developed rapid cook ovens using both microwave/convection and microwave/halogen combinations. In all cases, the manufacturers have attempted to avoid the food quality issues of microwave-only cooking by placing as high a priority on food quality as they do on rapid cooking.

One of the ways that manufacturers are addressing the food quality issue is by building advanced control systems into the ovens. These microprocessor controls give the user a high degree of flexibility over the source, location (top and bottom) and duration of the heat transfer process. This is essential to the success of these ovens since any inconsistency in the cooking process makes it impossible to produce consistent food over such short and intense cooking cycles. For instance, these ovens are capable of cooking food anywhere from 2 to 10 times faster than traditional appliances so any error in the cook time is amplified and can result in dramatically over- or under-cooked food. The positive result is that the advanced controls allow these ovens to consistently and repeatedly cook a wide variety of food products, from the robust to the delicate, with very little user interaction. The only real demand on the end user is to provide food product that is consistent in portion size and composition. While the end user may wish to develop the cooking programs for these food products, the rapid cook oven manufacturers typically have programming guides as part of their product literature and are usually willing to assist the end user in creating custom menus for specific food products.

Rapid cook ovens are different from traditional ovens because they are not controlled based on a temperature sensor in the oven cavity and there is no standard temperature for cooking a particular food product. Instead, the rapid cook ovens utilize a precisely timed cook cycle and vary the internal temperature as necessary to deliver just the right amount of heat to the food product. For example, if an end user were cooking pizza in a deck oven, the oven control would be set to a standard temperature of perhaps 475°F and the food product would be monitored until it was done. On subsequent cooking loads, the cook time might vary but the oven would still maintain an internal temperature of 475°F. The opposite is true for the rapid cook oven. In that case, the user would select a cooking program that would specify the power level, type of heat transfer and cook time. On subsequent cook loads in the rapid cook oven, the cook time

would remain exactly the same but the power level might vary to compensate for heat gained by the oven cavity during cooking. Once again, this cooking strategy is necessary to avoid over- or under-cooking the food.

One final aspect of the rapid cook oven that is different from traditional ovens is the manner in which they preheat and idle. A traditional oven is preheated to a set temperature before it is used to cook and in-between loads of food, when the oven is idling, it consumes energy to maintain the cavity temperature. Of the two ovens tested for this report, one operated exactly like a standard microwave oven, requiring no preheat before cooking and no idle energy between cook cycles – the oven was either on or off. The other rapid cook oven required a preheat that ended in a ready-to-cook state. This preheat was not based on a control setting but was instead required to bring part of the heat transfer mechanism to a ready-to-cook state. This preheat remained the same regardless of what food product was going to be cooked. In-between loads, this oven consumed only enough energy to maintain this heat transfer mechanism in the ready state.

Because rapid cook ovens represent a new appliance category, it was agreed that a standard test method for the performance of rapid cook ovens would benefit the food service industry. This test method would take advantage of any similarities that rapid cook ovens share with traditional ovens but would specifically address the unique performance characteristics of rapid cook ovens. Because of the diversity of rapid cook technologies, the test method would also be broad enough to cover all of the potential rapid cook oven designs.

With today's food service operators becoming more sophisticated in their choice of equipment, the demand for objective performance data has increased. The Food Service Technology Center project (FSTC) was started in 1986 to address this growing need for *unbiased* performance data on cooking equipment. With support from the Electric Power Research Institute (EPRI), the Gas Technology Institute (GTI), and the National Restaurant Association, and under the direction of the FSTC National Advisory Group, the FSTC research team develops standard test methods to evaluate the performance and energy consumption of gas and electric food service equipment.

To date, the FSTC has produced ratified ASTM standard test methods for over 20 different appliance categories, including various types of ovens.¹⁻²⁶ Advanced measurement techniques and automated data acquisition have contributed to a greater precision in reported test results for these test methods. With a greater emphasis on the repeatability of test results, a statistical treatment of data has been included as an integral part of the test methods.

In 1998 and 1999, the FSTC tested two different rapid cook ovens and published product evaluation reports on each.^{27,28} The results of these studies laid the initial groundwork for quantifying rapid cook oven performance using components of existing standardized cooking tests. This investigation follows-up those studies and discusses how the existing test procedures were combined and expanded upon in order to create the standard test method for rapid cook ovens.

OBJECTIVE AND SCOPE

The objective of this research was to develop a standard test method for evaluating the performance of gas and electric rapid cook ovens that would be impartial to energy source and could evolve as a recognized test method within the food service industry. Specific goals were to develop laboratory procedures that emulated typical appliance use in the field and that provided useful benchmark performance data for rapid cook ovens.

The scope of this investigation included:

1. Determination of a set of performance criteria that accurately described rapid cook oven energy usage.
2. Development of a repeatable cooking test for determining cooking-energy efficiency and production capacity.
3. Application of the draft test method to two rapid cook ovens to determine the preheat energy and time, idle energy rate, cooking energy rate, cooking-energy efficiency, and production capacity.

A glossary of terms used in this report appears in Appendix A and the draft test method for the performance of rapid cook ovens is in Appendix B.

Section 2

STM DEVELOPMENT

The goal of this research was to create a standard set of parameters for comparing the performance of rapid cook ovens that would be independent of fuel source. The ensuing test method was designed to be as simple and inexpensive as possible to perform while producing accurate, repeatable, and relevant information for end users. FSTC engineers resolved a variety of complex issues during the development of this test method. The investigation of these issues is discussed in detail in this section of the report.

TEST INSTRUMENTATION

Before beginning development of the test method, test instrumentation was selected and set up. The equipment specified in the test procedure was chosen with flexibility, availability, and accuracy in mind. The intent of the FSTC was to allow the tester to generate repeatable and accurate results, satisfying the uncertainty requirements mandated in the test procedure with a minimum of expensive or complex equipment. The following test instrumentation were used in the development and subsequent application of the draft test method:

- Type I canopy-style hood
- Constant voltage supply
- Energy meter
- Thermocouples
- Small weight scale (± 0.001 lb)
- Data acquisition system
- Computer and software
- Reach-in refrigerator
- Convection drying oven

For all test method development and subsequent rapid cook oven testing, the single canopy hood operated at a nominal 300 cfm/linear foot. There was at least 6 inches of clearance between the vertical plane of the appliance and the edge of the hood. Figure 2-1 illustrates the appliance and hood setup. In many instances, rapid cook ovens can be operated in restaurants without a ventilation hood; however, the FSTC researchers utilized the hood in order to maintain a consistent ambient temperature. The final test method does not require a specific hood configuration but does specify that the oven be installed in a properly ventilated area in accordance with the manufacturer's instructions. This allows for the possibility that a rapid cook oven may have an integrated grease removal/exhaust system, which would make the canopy exhaust hood unnecessary.

Power and electric energy were measured with a watt/watt-hour transducer that generated an analog signal for instantaneous power and a pulse for every 10 watt-hours. A voltage regulator was connected to the electric rapid cook ovens to maintain a constant 208 V for all tests. Both of the rapid cook ovens tested

were electric only. Had either oven required natural gas, the gas consumption would have been measured using a positive displacement-type gas meter that generates a pulse every 0.1 ft³. The energy meters, thermocouples, data logger and computer operated in tandem, measuring and recording elapsed time, temperatures, and energy or power. Data was collected and recorded using a Fluke Helios data logger with a direct serial connection to the computer. The testing software used to run the data logger and to time various events was developed by the FSTC using Microsoft® Visual Basic™ Professional Version. Appliance data (i.e., temperatures, energy signals) were recorded at 5-second intervals for all tests.

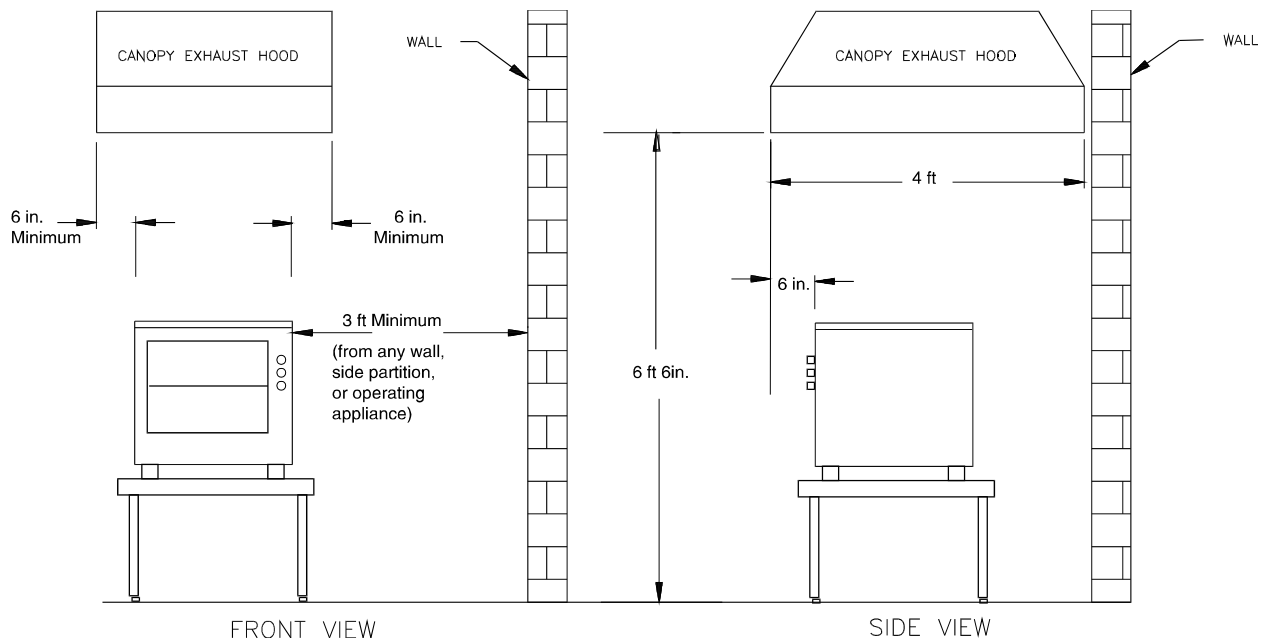


Figure 2-1. Appliance/hood configuration.

A small, accurate scale was required to measure the weight of the food product before and after the cooking-energy efficiency tests. Moisture content of the raw and cooked food was determined by drying the product over an extended period of time in a convection oven (Appendix C). The resulting moisture content of the raw and cooked food was used in analyzing the energy-to-food component of the cooking-energy efficiency calculations.

Appendix D contains an analysis of the measurement uncertainty for each cooking-energy efficiency test result, based on the measurement uncertainties in the various parameters used to calculate the test result (i.e., energy consumption, food weight, food temperature). This analysis was used, in part, to determine the required precision for the different instruments used in the test procedure.

SELECTION OF PERFORMANCE CRITERIA

Rapid cook ovens are very similar to both convection and deck ovens with several notable exceptions. First, the rapid cook oven may or may not need to be preheated and may or may not require idle energy consumption to remain in a ready to cook state. The rapid cook oven might use more than one heat transfer technology, requiring an input rate test for each type of heat generator (for example in microwave/convection ovens). It is typically very difficult to obtain the cavity temperature of a rapid cook oven with thermocouples due to either extreme heat or the use of microwaves. Also, the cavity temperature is not directly specified for the type of food being cooked. Likewise, the energy required to cook a food load in a rapid cook oven is not driven by the thermostat but is instead determined by the cooking program that is chosen. This means that light and medium sized food loads do not require significantly less energy than a heavy load. And finally, when a rapid cook oven is used to barrel-cook one food load after another, the energy required to cook each individual load will decline for the first several (4 to 6) loads before stabilizing. All of these performance characteristics are addressed in the test method.

The rapid cook oven test method includes tests and test foods that are similar to those found in the standard test methods for combination, deck, and conveyor ovens including measured energy input rate, pre-heat energy use and time and idle energy consumption (where applicable), a cook time determination test, and a cooking-energy efficiency and productivity test. The rapid cook oven test method differs from the other oven test methods in that it does not include a light or medium load food test. Instead, the test method includes a single run test for each of two food products, chicken breasts and pizza, and a barreling test for pizza.

COOKING-ENERGY EFFICIENCY SENSITIVITY

Research focused on the development of an energy efficiency test using typical food products so the data generated from this test would be meaningful to end-users. Several issues were explored in the course of developing a cooking test for rapid cook ovens including food product choice, endpoint determination, and equations for calculating the amount of energy absorbed by the food product during cooking and for calculating rapid cook oven cooking-energy efficiency.

Choice of Food Product

Pizza was the main food product that was used during the initial design, development, and promotion of rapid cook ovens and so it was a logical choice for one of the test food products. There was precedence for a cooking-energy efficiency test using a standardized pizza both within the standard test methods for

conveyor¹⁴ and deck ovens¹⁷ and the researchers were able to modify the procedure and apply it to the rapid cook oven test method.

Because rapid cook ovens are used for a wide variety of foods, it was decided that a second food product would also be included in the test method. Both hamburgers and chicken breasts were tested in the ovens during the test development and the energy efficiency and productivity numbers for each food product were comparable.²⁸ It was agreed that chicken breasts were the most representative food product and there was also precedence for chicken breast cooking-energy efficiency testing in the combination oven test method⁷ so this food product was also included in the rapid cook oven test method.

Endpoint Determination (Temperature Measurement)

The ingredients used for the test pizzas, the preparation of the test pizzas, and the criteria for pizza doneness were identical to those described in Sections 7.1 - 7.4 of ASTM designation F 1817-97, *Standard Test Method for the Performance of Conveyor Ovens*.¹⁴ Pizza doneness, as outlined by this ASTM standard, requires a final pizza temperature of $195 \pm 3^{\circ}\text{F}$. The final pizza temperature was measured by placing six hypodermic-style thermocouple probes on the surface of the pizza, located 3 inches from the center of the pizza and equidistant from each other, for a period of 60 seconds. The probes were allowed to penetrate the cheese and rest in the crust-sauce interface. The highest average temperature of the six probes during the 60-second period was the final pizza temperature. For consistency of the temperature readings, the probes were attached to a lightweight plastic disc that held the relative position of each probe constant from pizza to pizza. A picture of the thermocouple probe structure is shown in Fig 2-2.

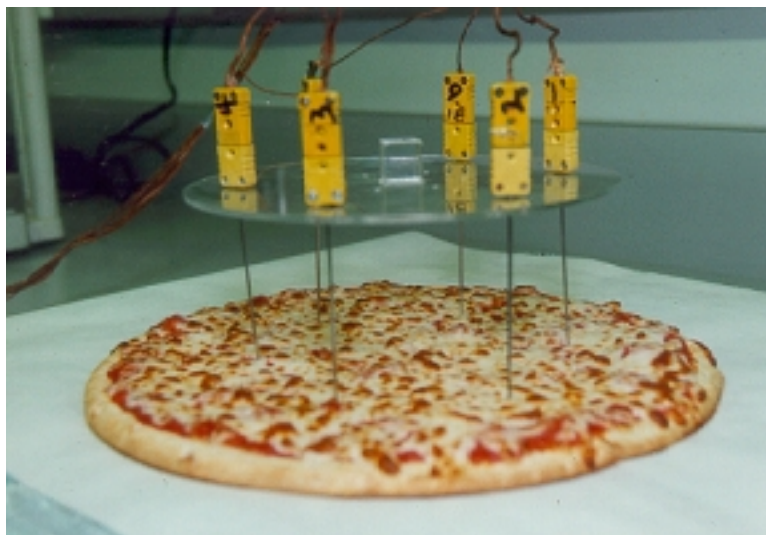


Figure 2-2. Thermocouple Probe Structure.

Likewise, the chicken breasts used, and the criteria for chicken doneness were the same as outlined in ASTM designation F1639-95, *Standard Test Method for the Performance of Combination Ovens*.⁷ Chicken doneness, as outlined by this standard, requires the internal chicken temperature to reach at least 170°F. Since it is not possible to thermocouple the chicken breasts while they are in the oven, the temperature of the thickest part of each breast was measured with a hypodermic-style thermocouple probe after cooking. The breasts were monitored for 60 seconds, and the highest average temperature recorded during this time was the final chicken temperature.

Cook Time Determination

Cook time determination tests were included in the test procedure for both the pizza and chicken breasts because it is impossible to instrument these food products with thermocouples during the cooking process. The researchers determined that once the cook time is determined for a specific food, it is unnecessary to readjust the oven's controls during the cooking tests. This is due to the rapid cook oven's ability to compensate for internal heat gained during repeated cook cycles, ensuring that the final temperature of the food will be relatively consistent.

The researchers found that one of the most crucial parts of the cook time determination was choosing the proper cooking control program. A rapid cook oven may be able to cook the test food products to the specified doneness using more than one control program or mix of heat transfer technologies. If the tester does not choose the most effective cooking program for the food product, then the results of the efficiency and productivity tests will not reflect the optimum performance of the rapid cook oven. For this reason, the test method specifies that the manufacturer's literature, and if necessary the manufacturer, shall be consulted in order to determine the cooking program that will cook the food product in the shortest amount of time and with the lowest energy consumption while maintaining the highest quality of the finished product.

Cooking-Energy Efficiency Calculation

Cooking-energy efficiency is a measure of how much of the energy consumed by an appliance is applied to useful work (i.e., cooking food). Specifically, cooking-energy efficiency is the ratio of energy added to the food and the energy supplied to the appliance during cooking, expressed as a percentage:

$$\text{Cooking - Energy Efficiency} = \frac{E_{\text{Food}}}{E_{\text{Appliance}}} \times 100\%$$

Energy absorbed by the food is calculated by determining:

- 1) how much heat was used to raise the temperature of the food from its starting condition to its cooked condition, or the sensible energy (E_{sens}),
- 2) how much heat was used to melt ice contained within the food product, or the fusion energy (E_{thaw}), and
- 3) how much heat was used to vaporize any moisture contained within the food product, or the vaporization energy (E_{vap}).

Both of the food products in the rapid cook test method, pizza and chicken breasts, are heated from a starting temperature of 40°F. Since this starting temperature is above the melting point for water, there is no energy required for fusion for either of these food products. So, the food energy is the sum of the sensible energy and the vaporization energy:

$$E_{food} = E_{sens} + E_{vap}$$

For the purposes of calculating the sensible energy, the chicken breasts may be broken down into three basic components: water, fat, and non-fat protein. The sensible heat can be defined as follows:

$$E_{sens} = \Sigma (W_i \times C_p \times (T_f - T_i))$$

where W_i is the initial weight of each specific component, T_f is the final average temperature of the chickens, T_i is the initial average temperature of chickens, and C_p is the specific heat of each component: 1.0 Btu/lb •°F for water, 0.4 Btu/lb •°F for fat, and 0.2 Btu/lb •°F for non-fat protein.²⁹

The specified chicken breasts for determining cooking-energy efficiency were composed of 74% moisture (water), 6% fat, and 20% nonfat protein. A weighted specific heat was determined for the test chicken breasts using these percentages:

$$\text{Weighted } C_p = \%_{water} \times C_{p,water} + \%_{fat} \times C_{p,fat} + \%_{protein} \times C_{p,protein}$$

The weighted specific heat for this composition was 0.80 Btu/lb•°F. Using this weighted specific heat for the chicken breasts greatly simplifies the sensible energy calculation:

$$E_{sens} = W_i \times C_{p,weighted} \times (T_f - T_i)$$

where W_i is the total initial weight of raw chicken and $C_{p,weighted}$ is the weighted specific heat for the test chicken breasts.

Energy due to vaporization represents a significant portion of the energy-to-food equation. Since the heat of vaporization for water is approximately twice the heat required to raise the chicken breasts from 40°F to 170°F, it was imperative to develop an accurate method for measuring the amount of moisture vaporized in the cooking process.

During the cooking process, a chicken breast loses weight by expelling moisture onto the surface of the container it is in and also by vaporizing water into the cavity of the oven. Because only part of the moisture is lost through vaporization, simply performing moisture analysis on samples of raw and cooked chickens will not account for the moisture that did not vaporize, which overestimates the vaporization energy. In order to accurately determine the amount of moisture that is vaporized, it is necessary to obtain the weight of the cooked chicken breast along with the moisture that is expelled and compare that to the weight of the raw chicken. This can be accomplished by weighing the chicken breasts along with the container they are cooked in both before and after cooking and including the moisture that is left in the container after cooking. The amount of water that was vaporized is the difference in the weight of the chicken breasts and container before and after cooking, or:

$$W_{loss} = W_i - (W_f + W_{drip})$$

where W_{loss} is the weight of water vaporized during cooking, W_i is the initial weight of the raw chicken breasts and the container they are cooked on, W_f is the final weight of the cooked chicken breasts and the container they are cooked on, and W_{drip} is the weight of the moisture that is left on the container after cooking.

The vaporization energy can then be defined as the product of the calculated weight loss and the heat of vaporization, as determined from the ASHRAE steam tables:²⁹

$$E_{vap} = W_{loss} \times H_v$$

where W_{loss} is the weight of water vaporized during the cooking process and H_v is the latent heat of vaporization for water.

Based on the three components of the test pizza (sauce, crust and cheese), the researchers were able to determine that the weighted specific heat for this composition was 0.593 Btu/lb·°F. As with the chicken breasts, the sensible energy calculation is:

$$E_{sens} = W_i \times C_{p,weighted} \times (T_f - T_i)$$

where W_i is the total initial weight of the pizza and $C_{p,weighted}$ is the weighted specific heat for the test pizza.

All of the weight loss to the pizza during the cooking process is due to vaporization of water into the oven cavity. Therefore, the amount of moisture that is vaporized can simply be calculated by weighing the pizza before and after cooking and the vaporization energy can then be defined as the product of the measured weight loss and the heat of vaporization, as determined from the ASHRAE steam tables:²⁹

$$E_{vap} = (W_i - W_f) \times H_v$$

where W_i is the initial weight of the uncooked pizza, W_f is the final weight of the cooked pizza and H_v is the latent heat of vaporization for water.

Energy to the Cooking Container

The manufacturers of rapid cook ovens often recommend specialized cooking surfaces or cooking containers for use in their ovens. In some cases, these specialized cooking containers are the only devices that can be used to cook certain food products in that oven. In other cases, the material composition of the cooking container might be limited by the use of microwaves in the oven. Since there is no one standard cooking container for all rapid cook ovens, it was decided to include the energy into the cooking container in the cooking-energy efficiency equation to account for differences in cooking container design and construction. By doing this, the energy efficiency equation more accurately reflects the energy balance of the cooking cycle. This approach is consistent with the *Standard Test Method for the Performance of Range Tops*,⁵ which includes the energy absorbed by the pots in the cooking-energy efficiency calculation. The energy to the cooking container may be calculated as follows:

$$E_{pan} = W_{pan} \times C_{p(pan)} \times (T_f - T_i)$$

where W_{pan} is the weight of the cooking container, $C_{p(pan)}$ is the specific heat of the cooking container and T_i and T_f are the average initial and final temperatures of the cooking container.

Since the total energy absorbed by the cooking container is small compared to the energy absorbed by the test food, the initial and final cooking container temperatures may be approximated using the initial and final food product temperatures. Though this practice may understate the cooking container energy, the

overall affect on the cooking-energy efficiency is minor. With the addition of the energy to the cooking container, cooking-energy efficiency is subsequently defined as:

$$\text{Cooking - Energy Efficiency} = \frac{E_{Food} + E_{pan}}{E_{Appliance}} \times 100\%$$

Some rapid cook oven manufacturers do not recommend that a cooking container be used when cooking pizza. In this case the cooking container energy would not be required for the energy efficiency calculation.

PRODUCTION CAPACITY AND PRODUCT SHRINKAGE

Since rapid cook ovens are designed to cook faster than traditional cooking techniques, production capacity is a particularly useful indicator of the oven's capabilities. To be consistent with other published ASTM test methods, production capacity will be reported in pounds per hour for both the chicken breasts and pizza as well as pizzas per hour. Product shrinkage, an indicator of the net product yield after cooking, is also reported for the chicken breasts.

BARRELING ENERGY PERFORMANCE

Because a rapid cook oven typically cooks the food product based on a specific timed interval as opposed to a strictly thermostatic control loop, the oven will often compensate for the accumulated heat gained during barreling cooking by reducing the cooking energy rate during the timed cook cycle. As a thermostatically controlled oven heats up, the cook time becomes shorter and the cooking energy rate remains the same but as a rapid cook oven heats up, the cook time remains the same and the cooking energy rate decreases resulting in an increase in energy efficiency. The barreling energy performance test determines how much the cooking energy rate decreases during barreling by heating the oven substantially with a series of pizza test loads. This information can then be used to estimate the energy requirements of the oven in a heavy use application and could be used to calculate the cooking-energy efficiency that the oven would achieve during heavy continuous usage while cooking either pizza or chicken breasts.

Section 3

STM APPLICATION

This section presents the results of applying the test method to two electric rapid cook ovens: a microwave-convection unit and a quartz halogen unit. Both appliances were heavy-duty models typical of those found in commercial food service operations.

EQUIPMENT

The rapid cook ovens loaned to the FSTC by manufacturers included:

Rapid cook oven A - A 10.8 kW, stainless steel, electric rapid cook oven.²⁷ Food is placed in the oven either directly on a ceramic cook platter or on a disposable pressware plate that sits on the ceramic platter, where it is simultaneously cooked by forced hot air and microwaves. The programmable computer control allows separate adjustment of both hot air flow rate and microwave intensity level and, the cooking program for each different food product can include up to four stages, called cook events. This oven includes a proprietary, integral, air filtering and catalytic grease scrubbing system.

Rapid cook oven B - An 11.9 kW, stainless steel, electric rapid cook oven.²⁸ Food is placed in the oven either directly on a rotating grill or on a special pyroceram dish that sits on the grill. High intensity quartz halogen lamps are positioned above and below the grill, at both center and outer positions creating cooking zones. Each zone can be programmed for a specific light intensity and duration during the cook cycle using one of the three cook modes: single-stage, two-stage, or pulse cooking.

The specifications for the two rapid cook ovens tested are listed for easy reference in Table 3-1.

Table 3-1.
Description of Rapid Cook Ovens Tested.

	Rapid Cook Oven A	Rapid Cook Oven B
Rated Input	10.8 kW	11.9 kW
Dimensions	31½" × 40" × 35½"	27½" × 21" × 19½"
Test Pizza (12 in.) Capacity	1 each	1 each
Test Chicken (5 oz) Capacity	6 each on pressware plate	5 each on pyroceram dish
Heat Source	microwave and convection	quartz halogen lamps

INPUT RATE

Prior to testing, the energy input rate for each rapid cook oven was measured and compared with the manufacturer's nameplate value. This procedure ensured that the rapid cook ovens were operating within specified parameters. Neither manufacturer of the rapid cook ovens that were tested recommended operating the ovens without a food load. Therefore, the energy input rate of Rapid cook oven A was measured by placing a microwave-safe dish filled with water into the oven. A recipe was programmed so the oven would run for 3 minutes with 100% hot air and 100% microwaves. Likewise, the energy input rate of Rapid cook oven B was measured by cooking a food load comprised of chicken breasts for 4.5 minutes, which provided the best opportunity to measure maximum energy consumption for the longest period of time. The measured energy input rates for Rapid cook oven A and Rapid cook oven B were 10.8 kW and 11.4 kW, both of which were within 5% of their respective nameplate ratings.

PREHEAT AND IDLE

Preheat time can be used by operators desiring to implement a start-up schedule. By knowing exactly how much time a rapid cook oven requires to achieve a ready-to-cook state, unnecessary idle time can be reduced. Rapid cook oven A required a preheat that ended in a ready-to-cook state. This preheat was not based on a control setting but was instead required to bring part of the heat transfer mechanism up to a standard temperature that was maintained as long as the oven was on. Rapid cook oven B operated exactly like a standard microwave oven, requiring no preheat before cooking.

The idle energy rate is a measure of the standby losses of a rapid cook oven while it maintains a ready-to-cook state. Rapid cook oven A consumed only enough energy while idling to maintain the required temperature of the heat transfer mechanism. Rapid cook oven B could be turned completely off between cook cycles and did not require any idle energy. If the oven's controls were left on, then a negligible amount of energy was consumed.

Table 3-2 summarizes the input rate, preheat, and idle test results for the two rapid cook ovens.

**Table 3-2.
Input Rate, Preheat, and Idle Test Results.**

	Rapid Cook Oven A	Rapid Cook Oven B
Measured Input Rate (kW)	10.8	11.4
Preheat:		
Time to ready-to-cook (min)	24.0	0.0
Energy (kWh)	2.48	0.0
Idle Energy Rate (kW)	0.98	0.0

COOKING-ENERGY EFFICIENCY AND PRODUCTION CAPACITY

During test method development, the rapid cook ovens were tested using pizza and chicken breasts, with both single run and barreling run test scenarios for each food product (i.e. single run pizza tests, barreling pizza test, single run chicken tests, barreling chicken test). The single run tests were used to determine the cooking-energy efficiency, production capacity and cooking energy rate of the rapid cook ovens. Energy consumption, elapsed cook time and ambient temperature were monitored for the duration of each cooking cycle at five-second intervals. After each cooking cycle, the final food product temperature was determined as well as the weight loss.

Single Run Pizza Test

The single run pizza test was designed to simulate a typical discrete cooking event in a rapid cook oven. A single pizza was weighed and then placed directly on the ceramic cook platter inside Rapid cook oven A and directly on the wire grill in Rapid cook oven B. No more than 1 minute was allowed to elapse from the time the pizza was removed from the refrigerator to the beginning of the cook cycle. After cooking, the pizza was removed from the oven and placed on a two-inch thick square of polystyrene insulation that prevented heat loss into the table surface during temperature measurement. After the final temperature was determined, the pizza was weighed again so that the weight loss due to vaporization could be calculated. The test was performed three times, allowing at least 5 minutes between tests so the oven would be cooking in a “from-idle” state.

Single Run Chicken Breasts Test

Chicken breasts were arranged on the cooking container and weighed, with the container, before cooking. For Rapid cook oven A, there were six chicken breasts placed on the pressware tray and for Rapid cook oven B, there were five chicken breasts placed in the pyroceram dish. No more than 1 minute was allowed to elapse between removal from the refrigerator and the beginning of the cook cycle. Immediately after

cooking, the chicken breasts were again weighed with the cooking container and the juices from cooking. The chicken breasts were then transferred to a wire drip rack, where they were probed for a period of 60 seconds to determine the final chicken temperature. Immediately following the temperature measurement, the breasts were weighed a final time, without the cooking container or juices, in order to determine both the weight loss due to vaporization and the product shrinkage. Once again, this test was performed three times with a minimum five-minute waiting period between tests. For the chicken breasts, the amount of shrinkage during cooking was reported, in addition to the cooking-energy efficiency, cooking energy rate and production capacity.

Cooking-Energy Efficiency and Production Capacity Test Results

Each of the single run tests for both pizza and chicken breasts were performed a minimum of three times and the uncertainty of the tests results was determined using a statistical analysis. The test procedure requires that the cooking-energy efficiency be reported with an uncertainty of less than $\pm 10\%$. A detailed description of the development of the statistical analysis method can be found in the Pacific Gas and Electric Company Research and Development report entitled *Development and Application of a Uniform Testing Procedure for Convection Ovens*.³⁰ The results from the single run tests for pizza and chicken breasts are presented in Table 3-3. Figures 3-4 and 3-5 illustrate the repeatability of the cooking-energy efficiency. Production capacity results do not vary from test to test due to the fact that each cook cycle is precisely timed and therefore every cook cycle during the test is exactly the same. Appendix E contains a synopsis of the test data for each replicate of the cooking tests.

Table 3-3.
Cooking-Energy Efficiency and Production Capacity Test Results.

	Rapid cook oven A	Rapid cook oven B
Single Run Pizza Test		
Load Size (Pizza/Load)	1	1
Cook Time (min)	1.2	2.5
Production Capacity (lb/h)	57.1	31.0
Production Capacity (pizza/h)	39.6	21.7
Cooking Energy Rate (kW)	9.0	7.2
Energy to Food (Btu)	198	181
Energy to Food (Btu/lb) ^a	136	128
Energy to Appliance (Wh)	180	300
Energy to Appliance (Btu/lb) ^a	423	723
Cooking-Energy Efficiency (%)	32.2 ± 0.4	17.7 ± 0.7
Percent Uncertainty	1.1	4.1
Single Run Chicken Breasts Test		
Load Size (Chickens/Load)	6	5
Cook Time (min)	1.6	4.5
Production Capacity (lb/h)	44.3	18.0
Product Shrinkage (%)	22.0	19.5
Cooking Energy Rate (kW)	10.6	11.1
Energy to Cooking Container (Btu)	NA ^b	203
Energy to Food (Btu)	300	366
Energy to Food (Btu/lb) ^a	201	241
Energy to Appliance (Wh)	280	833
Energy to Appliance (Btu/lb) ^a	641	1,873
Cooking-Energy Efficiency (%)	31.4 ± 1.0	20.0 ± 0.9
Percent Uncertainty	3.3	4.2

^a per pound of raw food product.

^b The energy imparted to the pressware cooking container during this test was negligible.

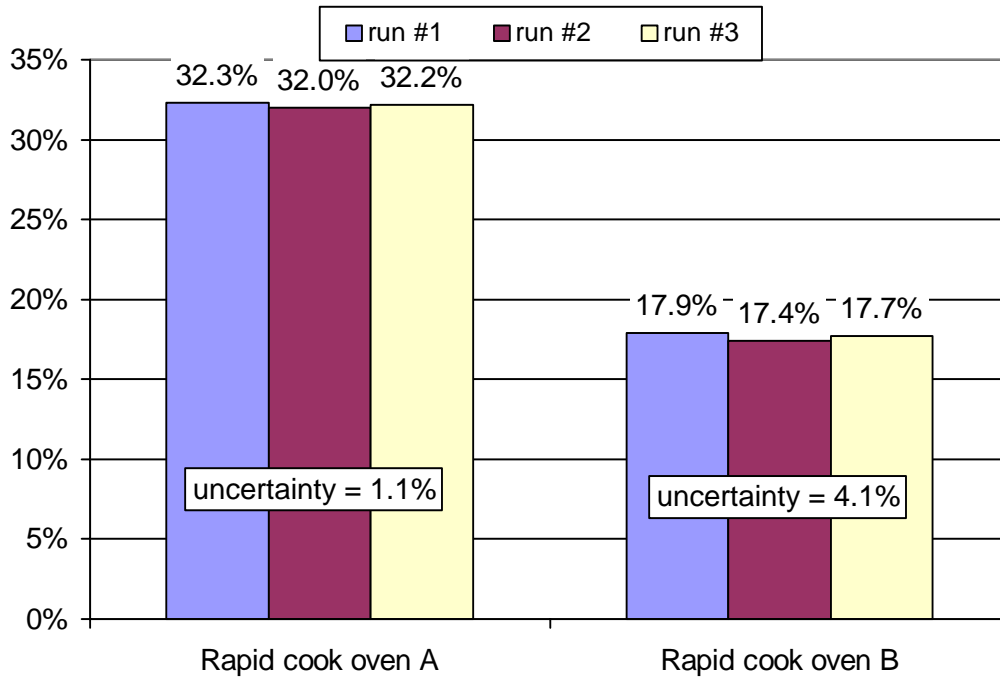


Figure 3-1. Single run pizza test cooking-energy efficiency repeatability.

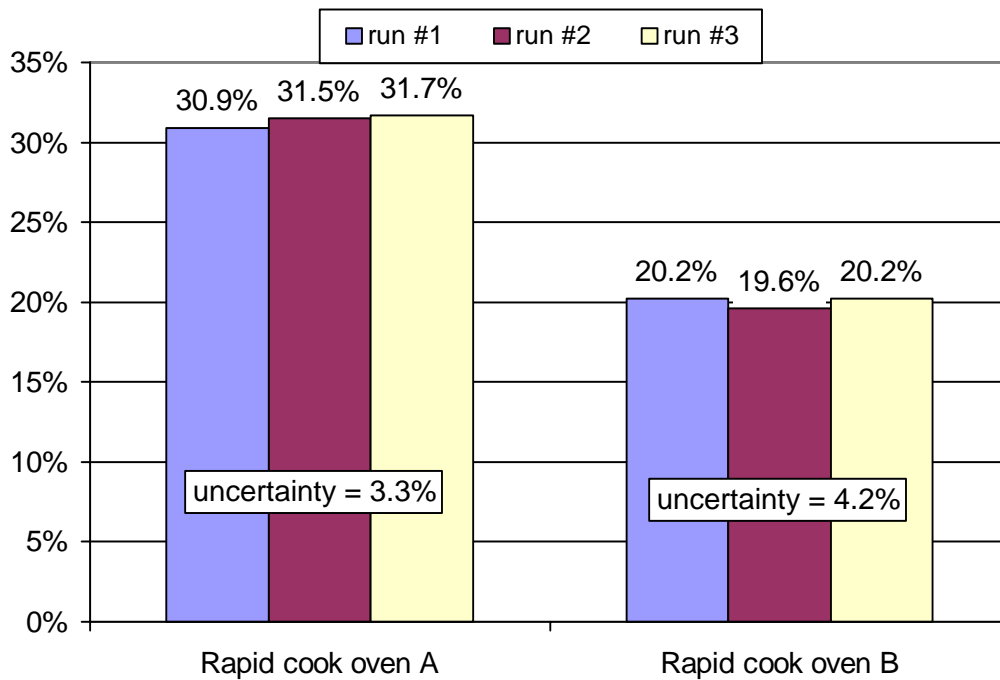


Figure 3-2. Single run chicken breast test cooking-energy efficiency repeatability.

The differences in performance between Rapid cook oven A and Rapid cook oven B are primarily due to the different kinds of heat transfer technologies employed by each of these two ovens. The microwave component of Rapid cook oven A appears to decrease the cook time for the test food significantly, resulting in a higher production rate and increased cooking-energy efficiency. These performance differences also reinforce the test method design by proving that each rapid cook oven has unique performance characteristics, which are highlighted by application of the cooking tests.

BARRELING ENERGY PERFORMANCE

As part of the test method development, the researchers performed one barreling energy performance test using pizza and one barreling test using chicken breasts on each of the two rapid cook ovens. The researchers determined through sensitivity testing that the cooking energy rate during barrel testing would decrease for each food load and stabilize at a fixed rate by the time 6 food loads had been cooked. For Rapid cook oven A, the cooking energy rate during pizza barrel testing decreased by 2.0 kW and the cooking energy rate during chicken barrel testing decreased by 2.2 kW. For Rapid cook oven B, the cooking energy rate during both pizza and chicken barrel testing decreased by 2.4 kW. The results from the barreling energy performance tests for pizza and chicken breasts are presented in Table 3-4. Figures 3-6 and 3-7 illustrate the change in the cooking energy rate for each food load during the barreling tests.

Table 3-4.
Barreling Test Results.

Food Load Number	Rapid cook oven A		Rapid cook oven B	
	Cooking Energy Rate (kW)		Cooking Energy Rate (kW)	
	Pizza	Chicken breasts	Pizza	Chicken breasts
<i>Load #1</i>	9.0	10.6	7.2	11.2
<i>Load #2</i>	9.0	9.9	7.2	9.6
<i>Load #3</i>	8.0	9.9	5.8	9.1
<i>Load #4</i>	8.0	8.4	5.8	9.1
<i>Load #5</i>	7.0	8.4	5.3	8.8
<i>Load #6</i>	7.0	8.4	4.8	8.8
Total energy rate reduction (kW)	2.0	2.2	2.4	2.4

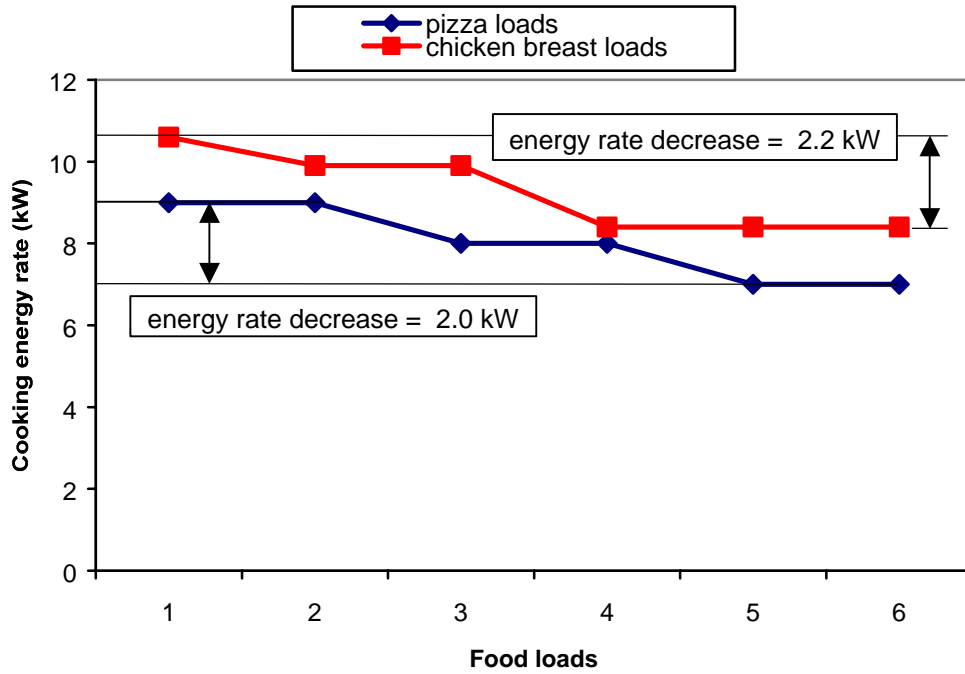


Figure 3-3. Barreling energy performance of Rapid cook oven A.

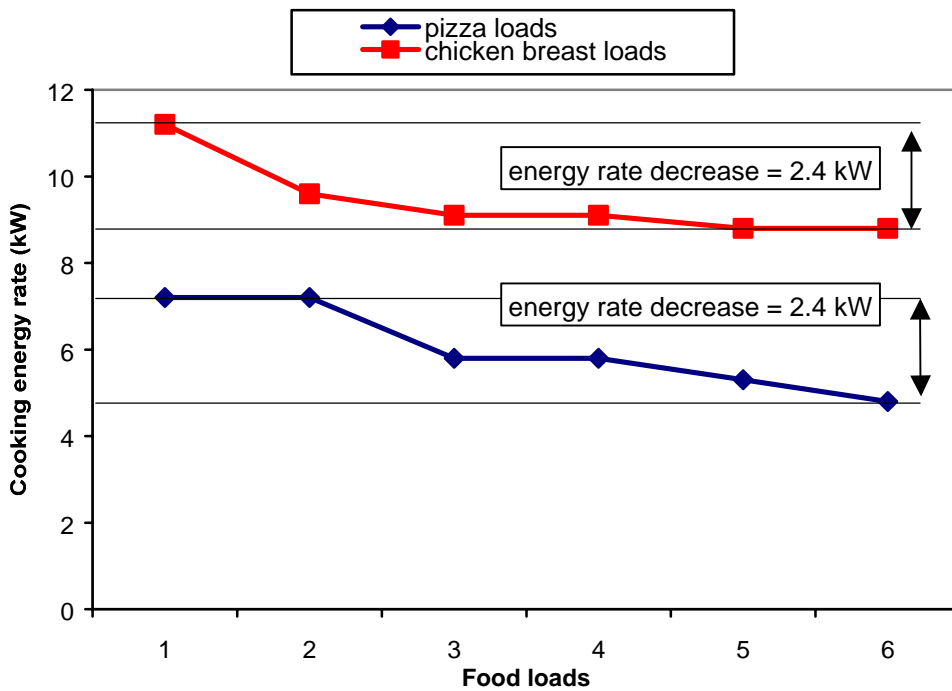


Figure 3-4. Barreling energy performance of Rapid cook oven B.

Because the cooking energy rate decreased by almost exactly the same amount for each rapid cook oven regardless of the food cooked, the researchers decided that the final test method should specify only one food product for the barreling energy performance test. Pizza was considered the most uniform test food product to work with and was therefore chosen for these tests. The researchers also modified the test method to specify that the barreling energy performance test be performed three times and that the reported cooking energy rate for each food load be the average of the three testing results for that food load.

Section 4

CONCLUSIONS

With the endorsement of the FSTC National Advisory Group, a draft test method was developed and recommended as a valid method for evaluating and comparing the performance of rapid cook ovens. The draft test method for rapid cook ovens was submitted to ASTM at the Spring 2000 meeting for consideration as a test method within its standards for food service equipment. The procedure, as submitted, is included in Appendix B of this report.

THE NEED FOR A TEST METHOD

If all rapid cook ovens had the same operating and performance characteristics, there would be no need for a standard test method. Because of the different approaches each manufacturer has chosen in designing their rapid cook ovens, these ovens have different performance and energy consumption characteristics and a standard test method is justified. Facility designers and equipment specifiers can use the unbiased performance data generated by a standard test method as an important tool for choosing the right rapid cook oven for a given end use. A standard test method also provides benchmark data so that improved designs can be effectively documented and designers and manufacturers can show value and be rewarded for their innovations. The information generated by the standard test method, when combined with standard appliance energy consumption calculations, provides a complete picture of the performance of a rapid cook oven and allows for fair and accurate comparison.

RECOMMENDED FUTURE WORK

The draft test method was developed using small footprint, electric, rapid cook ovens—the only type of rapid cook oven available on the market at the time. While differences in performance between units were apparent, the test method may not take into account possible requirements of testing larger rapid ovens that might be developed in the future. When, and if, these larger models are developed, additional testing may be required to ensure that the test method remains pertinent to all the available models of rapid cook ovens.

Section 5

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Appendix A
GLOSSARY

GLOSSARY

Cooking Energy (kWh or kBtu)

The total energy consumed by an appliance as it is used to cook a specified food product.

Cooking Energy Consumption Rate (kW or kBtu/h)

The average rate of energy consumption during the cooking period.

Cooking-Energy Efficiency (%)

The quantity of energy input to the food products; expressed as a percentage of the quantity of energy input to the appliance during cooking-energy efficiency tests.

$$\text{Cooking-Energy Efficiency} = \frac{\text{Energy to Food}}{\text{Energy to Appliance}} \times 100$$

Duty Cycle (%)

Energy Factor
Load Factor

The average energy consumption rate (based on a specified operating period for the appliance) expressed as a percentage of the measured energy input rate.

$$\text{Duty Cycle} = \frac{\text{Average Energy Consumption Rate}}{\text{Measured Energy Input Rate}} \times 100$$

Energy Input Rate (kW or kBtu/h)

Energy Consumption Rate
Energy Rate

The peak rate at which an appliance will consume energy, typically reflected during preheat.

Heating Value (Btu/ft³)

Heating Content

The quantity of heat (energy) generated by the combustion of fuel. For natural gas, this quantity varies depending on the constituents of the gas.

Idle Duty Cycle (%)

Idle Energy Factor

The idle energy consumption rate expressed as a percentage of the measured energy input rate.

$$\text{Idle Duty Cycle} = \frac{\text{Idle Energy Consumption Rate}}{\text{Measured Energy Input Rate}} \times 100$$

Idle Energy Rate (kW or Btu/h)

Idle Energy Input Rate
Idle Rate

The rate of appliance energy consumption while it is holding or maintaining a stabilized operating condition or temperature.

Idle Temperature (°F, Setting)

The temperature of the cooking cavity/surface (selected by the appliance operator or specified for a controlled test) that is maintained by the appliance under an idle condition.

Measured Input Rate (kW or Btu/h)

Measured Energy Input Rate
Measured Peak Energy Input Rate

The maximum or peak rate at which an appliance consumes energy, typically reflected during appliance preheat (i.e., the period of operation when all burners or elements are “on”).

Pilot Energy Rate (kBtu/h)

Pilot Energy Consumption Rate

The rate of energy consumption by the standing or constant pilot while the appliance is not being operated (i.e., when the thermostats or control knobs have been turned off by the food service operator).

Preheat Energy (kWh or Btu)

Preheat Energy Consumption

The total amount of energy consumed by an appliance during the preheat period.

Preheat Rate (°F/min)

The rate at which the cook zone heats during a preheat.

Preheat Time (minute)

Preheat Period

The time required for an appliance to warm from the ambient room temperature ($75 \pm 5^\circ\text{F}$) to a ready-to-cook state.

Production Capacity (lb/h)

The maximum production rate of an appliance while cooking a specified food product in accordance with the cooking-energy efficiency test.

Production Rate (lb/h)

Productivity

The average rate at which an appliance brings a specified food product to a specified “cooked” condition.

Rated Energy Input Rate (kW or Btu/h)

Input Rating (ANSI definition)
Nameplate Energy Input Rate
Rated Input

The maximum or peak rate at which an appliance consumes energy as rated by the manufacturer and specified on the nameplate.

Recovery Time (minute, second)

The time from the removal of the test food product from the oven until the oven has returned to a ready-to-cook state.

Test Method

A definitive procedure for the identification, measurement, and evaluation of one or more qualities, characteristics, or properties of a material, product, system, or service that produces a test result.

Appendix B

**DRAFT STANDARD TEST METHOD
FOR THE PERFORMANCE OF RAPID COOK OVENS**

As submitted to the Subcommittee F26.06 on Productivity and Energy Protocols of the ASTM F-26
Committee on Food Service Equipment.

Standard Test Method for the Performance of Rapid Cook Ovens

1. Scope

1.1 This test method evaluates the energy consumption and cooking performance of rapid cook ovens. The food service operator can use this evaluation to select a rapid cook oven and understand its energy consumption.

1.2 This test method is applicable to gas and electric rapid cook ovens.

1.3 The rapid cook oven can be evaluated with respect to the following (where applicable):

1.3.1 Energy input rate (Section 10.2)

1.3.2 Preheat energy consumption and time (Section 10.3)

1.3.3 Idle energy rate (Section 10.4)

1.3.4 Pilot energy rate (if applicable) (Section 10.5)

1.3.5 Cooking-energy efficiency, cooking-load energy efficiency and production capacity (Section 10.6)

1.4 The values stated in inch-pound units are to be regarded as standard. The SI units given in parentheses are for information only.

1.5 *This test method may involve hazardous materials, operations, and equipment. This test method does not purport to address all of the potential safety problems associated with its use. It is the responsibility of the users of this test method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to its use.*

2. Referenced Documents

2.1 *ASHRAE Documents:*

ASHRAE Handbook of Fundamentals, “Thermal and Related Properties of Food and Food Materials,” Chapter 30, Table 1, 1989.

ASHRAE Guideline 2-1986 (RA90) Engineering Analysis of Experimental Data

3. Terminology

3.1 *Definitions:*

3.1.1 *rapid cook oven*, n—a cooking appliance that utilizes one or more heat transfer technologies to cook food product within a chamber and which is capable of cooking the food product significantly faster than is possible using solely radiant oven or convection oven technologies. Heat transfer technologies which may be employed include microwave, quartz halogen and high velocity or impingement convection, both gas and electric.

3.1.2 *cooking-energy efficiency*, n—quantity of energy imparted to the specified food product, expressed as a percentage of energy consumed by the rapid cook oven during the cooking event.

3.1.3 *cooking-load energy efficiency*, n—quantity of energy imparted to the specified food product and the pot, pan, tray, or dish containing the food product, expressed as a percentage of energy consumed by the rapid cook oven during the cooking event.

3.1.4 *cooking energy rate*, n—average rate of energy consumption (Btu/h or kW) during the cooking-energy efficiency tests. Refers to all loading scenarios (heavy, medium, light).

3.1.5 *energy input rate*, n—peak rate at which a rapid cook oven consumes energy (Btu/h or kW).

3.1.6 *idle energy rate*, n—the rapid cook oven’s rate of energy consumption (kW or Btu/h), when empty, required to maintain its cavity temperature at the specified thermostat set point or to otherwise maintain the oven in a ready-to-cook condition.

3.1.7 *oven cavity*, n —that portion of the rapid cook oven in which food products are heated or cooked.

3.1.8 *pilot energy rate*, n —rate of energy consumption (Btu/h) by a rapid cook oven's continuous pilot (if applicable).

3.1.9 *preheat energy*, n —amount of energy consumed (Btu or kWh), by the rapid cook oven while preheating its cavity from ambient temperature to the specified thermostat set point or while preheating any other component of the oven, for example an integral heat exchanger, to a ready-to-cook condition.

3.1.10 *preheat time*, n —time (min.) required for the rapid cook oven cavity to preheat from ambient temperature to the specified thermostat set point or for the rapid cook oven to achieve a ready-to-cook condition.

3.1.11 *production capacity*, n —maximum rate (lb/h) at which a rapid cook oven can bring the specified food product to a specified "cooked" condition.

3.1.12 *production rate*, n —rate (lb/h) at which a rapid cook oven brings the specified food product to a specified "cooked" condition. Does not necessarily refer to maximum rate. Production rate varies with the amount of food being cooked.

3.1.13 *uncertainty*, n —measure of systematic and precision errors in specified instrumentation or measure of repeatability of a reported test result.

4. Summary of Test Method

4.1 Energy input rate is determined to confirm that the rapid cook oven is operating within 5% of the nameplate energy input rate. For a gas rapid cook oven, the pilot energy rate and the fan and control energy rates are also determined.

4.3 Preheat energy and time are determined.

4.4 Idle energy rate is determined.

4.5 Cooking-energy efficiency, cooking-load energy efficiency and production rate are determined during single-run and barreling-run cooking tests using pizza and chicken breasts as food products.

5. Significance and Use

5.1 The energy input rate test is used to confirm that the rapid cook oven is operating properly prior to further testing.

5.2 Preheat energy and time can be useful to food service operators to manage power demands and to know how quickly the rapid cook oven can be ready for operation.

5.3 Idle energy rate and pilot energy rate can be used to estimate energy consumption during non-cooking periods.

5.4 Cooking-energy efficiency is a precise indicator of a rapid cook oven's energy performance while cooking a typical food product under various loading conditions. If energy performance information is desired using a food product other than the specified test food, the test method could be adapted and applied. Energy performance information allows an end user to better understand the operating characteristics of a rapid cook oven.

5.5 Production capacity information can help an end user to better understand the production capabilities of a rapid cook oven as it is used to cook a typical food product and this could help in specifying the proper size and quantity of equipment. If production information is desired using a food product other than the specified test food, the test method could be adapted and applied.

6. Apparatus

6.1 *Analytical Balance Scale*, for measuring weights up to 20 lb, with a resolution of 0.01 lb and an uncertainty of 0.01 lb.

6.2 *Barometer*, for measuring absolute atmospheric pressure, to be used for adjustment of measured natural gas volume to standard conditions. Shall have a resolution of 0.2 in. Hg and an uncertainty of 0.2 in. Hg.

6.3 *Canopy Exhaust Hood*, 4 ft in depth, wall-mounted with the lower edge of the hood 6 ft, 6 in. from the floor and with the capacity to operate at a nominal exhaust ventilation rate of 300 cfm per linear foot of active hood length. This hood shall extend a minimum of 6 in. past both sides and the front of the cooking appliance and shall not incorporate side curtains or partitions.

6.4 *Convection Drying Oven*, with temperature controlled at $220 \pm 5^\circ\text{F}$, to be used to determine moisture content of pizza crust, pizza sauce and pizza cheese.

6.5 *Gas Meter*, for measuring the gas consumption of a rapid cook oven, shall be a positive displacement type with a resolution of at least 0.01 ft^3 and a maximum uncertainty no greater than 1% of the measured value for any demand greater than $2.2 \text{ ft}^3/\text{h}$. If the meter is used for measuring the gas consumed by the pilot lights, it shall have a resolution of at least 0.01 ft^3 and a maximum uncertainty no greater than 2% of the measured value.

6.6 *Pressure Gage*, for monitoring natural gas pressure. Shall have a range of zero to 10 in. H_2O , a resolution of 0.5 in. H_2O , and a maximum uncertainty of 1% of the measured value.

6.7 *Stop Watch*, with a 1-sec resolution.

6.8 *Temperature Sensor*, for measuring natural gas temperature in the range of 50°F to 100°F with an uncertainty of $\pm 1^\circ\text{F}$.

6.9 *Thermocouple*, fiberglass insulated, 24 gage, type K thermocouple wire, connected at the exposed ends by tightly twisting or soldering the two wires together.

6.10 *Thermocouple Probe*, type K, micro needle, product probe with a response time from ambient to 200°F of less than 20 seconds.

6.11 *Watt-Hour Meter*, for measuring the electrical energy consumption of a rapid cook oven, shall have a resolution of at least 10 Wh and a maximum uncertainty no greater than 1.5% of the measured value for any demand greater than 100 W. For any demand less than 100 W, the meter shall have a resolution of at least 10 Wh and a maximum uncertainty no greater than 10%.

7. Reagents and Materials

7.1 *Chicken breasts* shall be nominal 5 oz. frozen, boneless, skinless, butterfly cut, chicken breasts (whole meat - not fabricated). When thawed and drained, each chicken breast shall weigh $4.8 \pm 0.2 \text{ oz}$.

7.2 *Pizza Crust* shall be a 12 inch diameter, prebaked or parbaked crust, weighing $0.9 \pm 0.2 \text{ lb}$ and having a moisture content of $36 \pm 3\%$ by weight, based on a gravimetric moisture analysis. Refrigerate to $39 \pm 1^\circ\text{F}$.

7.3 *Pizza Sauce* shall be a simple, tomato based sauce with a moisture content of $90 \pm 2\%$ by weight, based on a gravimetric moisture analysis. Refrigerate to $39 \pm 1^\circ\text{F}$.

7.4 *Pizza Cheese* shall be a part skim, low moisture, shredded mozzarella cheese with a moisture content of $50 \pm 2\%$ by weight, based on a gravimetric moisture analysis. Refrigerate to $39 \pm 1^\circ\text{F}$.

7.5 *Pizza* shall be comprised of a pizza crust, pizza sauce and pizza cheese according to the following: uniformly spread 0.25 lb of pizza sauce on top of a pizza crust to within 0.5 inch of the edge of the crust and cover the pizza sauce with 0.375 lb of pizza cheese.

7.6 Gravimetric moisture analysis shall be performed as follows: To determine moisture content, place a 1 lb. sample of the test food on a dry, aluminum sheet pan and place the pan in a convection drying oven at a temperature of $220 \pm 5^\circ\text{F}$ for a period of 24 hours. Weigh the sample before it is placed in the oven and after it is removed and determine the percent moisture content based on the percent weight loss of the sample. The sample must be thoroughly chopped (1/8 inch or smaller squares) and spread evenly over the surface of the sheet pan in order for all of the moisture to evaporate during drying and it is permissible to spread the sample on top of baking paper in order to protect the sheet pan and simplify clean-up.

NOTE 1—The moisture content of pizza crust, pizza sauce, and pizza cheese can be determined by a qualified chemistry lab using the AOAC procedure 984.25 Moisture (Loss of Mass on Drying) in Frozen French Fried Potatoes.

8. Sampling, Test Units

8.1 *Rapid cook oven*—Select a representative production model for performance testing.

9. Preparation of Apparatus

9.1 Install the appliance in a properly ventilated area in accordance with the manufacturer's instructions. The associated heating or cooling system shall be capable of maintaining an ambient temperature of $75 \pm 5^\circ\text{F}$ within the testing environment.

NOTE 2— The ambient temperature requirements are designed to simulate real world kitchen temperatures and are meant to provide a reasonable guideline for the temperature requirements during testing. If a facility is not able to maintain the required temperatures, then it is reasonable to expect that the application of the procedure may deviate from the specified requirements (if it cannot be avoided) as long as those deviations are noted on the Results Reporting Sheets.

9.2 Connect the rapid cook oven to a calibrated energy test meter. For gas installations, install a pressure regulator downstream from the meter to maintain a constant pressure of gas for all tests. Install instrumentation to record both the pressure and temperature of the gas supplied to the rapid cook oven and the barometric pressure during each test so that the measured gas flow can be corrected to standard conditions. For electric installations, a voltage regulator may be required during tests if the voltage supply is not within $\pm 2.5\%$ of the manufacturer's nameplate voltage.

9.3 For an electric rapid cook oven, confirm (while the rapid cook oven elements are energized) that the supply voltage is within $\pm 2.5\%$ of the operating voltage specified by the manufacturer. Record the test voltage for each test.

NOTE 3—If an electric rapid cook oven is rated for dual voltage (e.g., 208/240 V), the rapid cook oven shall be evaluated as two separate appliances in accordance with this standard test method.

9.4 For a gas rapid cook oven, adjust (during maximum energy input) the gas supply pressure downstream from the appliance's pressure regulator to within $\pm 2.5\%$ of the operating manifold pressure specified by the manufacturer. Make adjustments to the appliance following the manufacturer's recommendations for optimizing combustion.

10. Procedure

10.1 *General:*

10.1.1 For gas appliances, record the following for each test run:

- 1) Higher heating value
- 2) Standard gas pressure and temperature used to correct measured gas volume to standard conditions.
- 3) Measured gas temperature
- 4) Measured gas pressure

- 5) Barometric pressure
- 6) Energy input rate during or immediately prior to test (for example, during the preheat for that days testing)

NOTE 4—Using a calorimeter or gas chromatograph in accordance with accepted laboratory procedures is the preferred method for determining the higher heating value of gas supplied to the rapid cook oven under test. It is recommended that all testing be performed with gas having a higher heating value of 1000 to 1075 Btu/ft³.

10.1.2 For gas rapid cook ovens, add electric energy consumption to gas energy for all tests, with the exception of the energy input rate test (section 10.3).

10.1.3 For electric rapid cook ovens, record the following for each test run:

- 1) Voltage while elements are energized
- 2) Energy input rate during or immediately prior to test (for example, during the preheat for that days testing)

10.1.4 For each test run, confirm that the peak input rate is within $\pm 5\%$ of the rated nameplate input. If the difference is greater than 5%, terminate testing and contact the manufacturer. The manufacturer may make appropriate changes or adjustments to the rapid cook oven.

10.2 *Energy Input:*

10.2.1 Set the rapid cook oven controls so that the oven will operate at the maximum input rate and turn the oven on.

10.2.2 Record the time and energy consumption starting as soon as the elements or burners cycle on and continuing over a period that is long enough to accurately determine the energy input rate of the oven. The oven must be fully on over the entire period and the test period must end when any of the burners or elements first cycle off.

NOTE 5—The rapid cook oven may be equipped with a high temperature limit control which prematurely cycles the oven off if no food load is present in the oven cavity. In this case, the researcher may select an appropriate food load which will allow the oven to operate for the duration of the test period.

10.2.3 Calculate and record the rapid cook oven's energy input rate and compare the result to the rated nameplate input. For gas rapid cook ovens, the burner energy consumption is used to compare the calculated energy input rate with the rated gas input and any electrical energy consumption shall be used to compare the calculated energy input rate with the rated electrical input.

10.2.7 In accordance with section 11.4, calculate and report the rapid cook oven energy input rate and rated nameplate input.

10.3 *Preheat Energy Consumption and Time:*

10.3.1 Determine whether the rapid cook oven requires preheating in order to achieve a ready-to-cook state. If the oven requires preheating, verify that the oven cavity temperature is $75 \pm 5^\circ\text{F}$ and turn the rapid cook oven on.

10.3.2 Record the time and energy consumption required to preheat the rapid cook oven, from the time when the unit is turned on until the time when the rapid cook oven achieves a ready-to-cook state.

10.3.3 In accordance with section 11.5, calculate and report the preheat energy consumption and time.

10.4 *Idle Energy Rate:*

10.4.1 Turn the rapid cook oven on and allow it to achieve a ready-to-cook state. If the oven requires preheating in order to achieve a ready-to-cook state then allow the oven to idle for 60 min. after it is fully preheated.

10.4.2 Begin recording the rapid cook oven's idle energy consumption for a minimum of 2 hr. Record the length of the idle period.

10.4.3 In accordance with section 11.6, calculate and report the rapid cook oven's idle energy rate.

NOTE 6—For a rapid cook oven that does not require preheat, the idle energy rate will consist of the computer controls, control circuits, fans, and any other energy consumption that is required to keep the unit in a standby or ready-to-cook state.

10.5 *Pilot Energy Rate:*

10.5.1 For a gas rapid cook oven with a standing pilot, set the gas valve at the "pilot" position and set the rapid cook oven's temperature control to the "off" position.

10.5.2 Light and adjust the pilot according to the manufacturer's instructions.

10.5.3 Monitor gas consumption for a minimum of 8 hr. of pilot operation.

10.5.4 In accordance with section 11.7, calculate and report the pilot energy rate.

10.6 *Pizza and Chicken Breast Preparation:*

10.6.1 Prepare 27 pizzas in accordance with 7.4. Three of these pizzas will be used for single-run cooking-energy efficiency tests and the remaining 24 will be used for barreling-run tests. Cover the pizzas with plastic wrap (to inhibit moisture loss), place in a refrigerator and chill the pizzas until they stabilize at $39 \pm 1^\circ\text{F}$. Do not test with pizzas that have been in the refrigerator more than 24 hours. Each pizza will comprise a pizza test load.

NOTE 7— The test pizzas should not be stored in the refrigerator for long periods, more than 24 hours, because the pizza crust may absorb excessive moisture from the sauce and evaporation may reduce the moisture content of the sauce, changing the thermal characteristics of the pizza. The 24-hour period is a practical "time" specification that allows the preparation of test pizzas on day one, overnight chilling and stabilization and application of the procedure the following day.

NOTE 8—In order to easily handle and store the pizzas, it is recommended that the prepared pizzas be placed on full size (18 x 26 inch) sheet pans, two pizzas per pan. The entire pan can then be covered with food grade plastic wrap. When stacking multiple pans in the refrigerator, spacers are necessary between the pans in order to protect the pizzas from damage. Researchers at Pacific Gas and Electric Company's Food Service Technology Center have found that sauce cups can be used as spacers.

NOTE 9—A minimum of 3 test runs is specified, however, more test runs may be necessary if the results do not meet the uncertainty criteria specified in Annex A.1.

10.6.2 Prepare a minimum of 4 additional pizzas for use in cook time determination. The actual number of pizzas needed for the cook time determination will vary with the number of trials needed to establish a cooking time that demonstrates a $195 \pm 3^\circ\text{F}$ final pizza temperature after cooking.

10.6.3 Determine how many thawed, whole chicken breasts can be placed on the manufacturer's recommended cooking container. The chicken breasts must be spread open and must be placed so as to cover as much of the bottom surface area of the cooking container as possible without allowing any part of two adjacent chicken breasts to overlap. Use only whole chicken breasts as specified in 7.1. Record the number of chicken breasts used. This amount of chicken breasts will comprise a chicken test load.

10.6.4 Thaw enough chicken breasts, as specified in 7.1, for a minimum of seven, chicken test loads. Four of these loads will be used for cook time determination and the remaining three loads will be used for single-run cooking-energy efficiency tests. The actual number of chicken breasts needed for the cook time determination will vary

with the number of trials needed to establish a cooking time that demonstrates a $170 \pm 3^\circ\text{F}$ internal temperature after cooking. Arrange the thawed chicken breasts in a single layer on wire racks so that the chicken breasts will drain and place the wire racks on sheet pans inside of a refrigerator. Cover the sheet pans with plastic wrap and allow the chicken breasts to stabilize in the refrigerator for a minimum of 24 hours in order to ensure a uniform internal temperature of $39 \pm 1^\circ\text{F}$. Do not store the thawed chicken breasts in the refrigerator for more than one week.

NOTE 10—A minimum of 3 test runs is specified, however, more test runs may be necessary if the results do not meet the uncertainty criteria specified in Annex A.1.

NOTE 11—It is suggested that the frozen chicken breasts be thawed in cold running water.

NOTE 12—It is important that the raw chicken breasts be properly and consistently thawed and drained. Excess moisture on the cooking utensil will make it difficult to accurately determine the amount of product shrinkage.

10.7 Cook Time Determination:

10.7.1 Turn the rapid cook oven on and allow it to achieve a ready-to-cook state. If the oven requires preheating in order to achieve a ready-to-cook state then allow the oven to idle for 60 min. after it is fully preheated. Set the rapid cook oven controls to the manufacturer's recommended setting for cooking a parbaked pizza as specified in 7.4. Estimate a cook time for pizza.

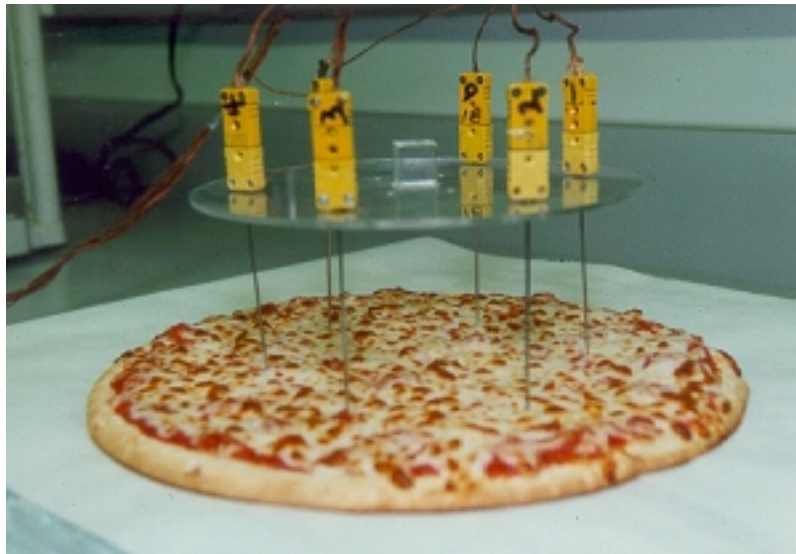
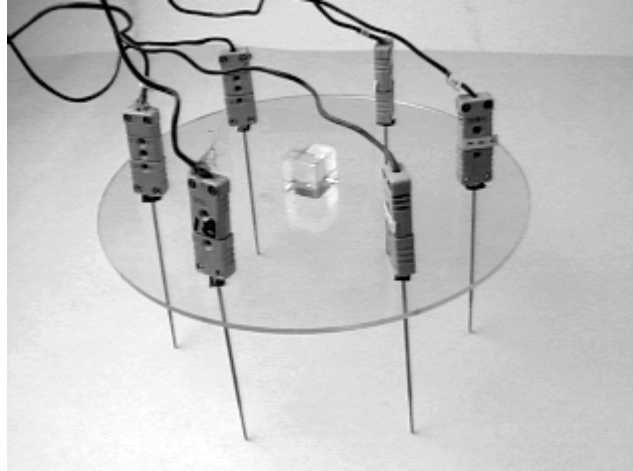
NOTE 13—The rapid cook oven may allow for several different recipes or programs which will all cook the test pizza to an adequate doneness. The researcher should choose the recipe or program that cooks the pizza in the shortest amount of time and with the lowest energy consumption while maintaining the highest quality of the finished pizza. The manufacturer can be a valuable resource in optimizing this cooking process and should be consulted where possible.

10.7.2 Remove a pizza test load (a single pizza) from the refrigerator and place the pizza directly on the manufacturer's recommended cooking surface or cooking container in the center of the oven. If the manufacturer does not recommend a cooking surface or cooking container for cooking parbaked pizza then place the pizza directly on the oven deck. Do not allow more than 1 minute to elapse from the time a pizza is removed from the refrigerator until it is placed in the oven.

10.7.3 Allow the pizza to cook for the duration of the estimated cook time and then remove the pizza from the rapid cook oven and place the pizza on an insulated, non-metallic surface such as corrugated cardboard. A standard cardboard pizza box is acceptable.

10.7.4 Determine the final temperature of the pizza by placing six thermocouple probes on the surface of the pizza. Locate the probes 3 inches from the center of the pizza and spaced equidistant from each other as shown in Figure 1. The probes should penetrate the cheese and rest on the sauce-crust interface directly beneath the cheese. Allow no more than 10 seconds from the time the pizza is removed from the oven to the time the probes are placed on the pizza. Leave the probes in place on the pizza and record and average the temperatures of all six probes every five seconds over a one minute period (for a total of 12 readings). The final pizza temperature is the highest average temperature of the six probes during the one minute period. If the final pizza temperature is not $195 \pm 3^\circ\text{F}$, adjust the cook time and repeat the cook time determination test as necessary to produce a $195 \pm 3^\circ\text{F}$ final temperature.

NOTE 14—It is recommended that the six thermocouple probes be attached to a simple, lightweight, rigid structure which will maintain the proper spacing and upright position of the probes and will therefore help maintain the consistency of the temperature readings. The following photographs show a thermocouple structure which is made of Plexiglas and includes a simple handle for easy placement of the structure on the pizza.



This structure can be gently set on top of the pizza during cook time determination with just enough force to penetrate the cheese but not enough to push the probes beyond the sauce-crust interface. Because the sauce migrates into the crust during cooking, it is relatively easy to remain in the sauce-crust interface during temperature measurement.

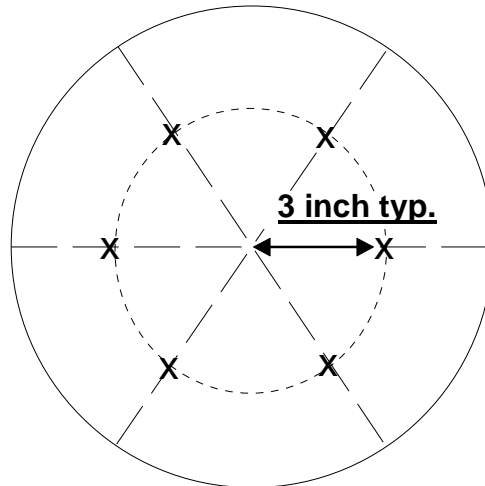


Figure 1. Location of thermocouple probes on pizza surface.

10.7.5 Record the determined cook time and the recipe or program for optimized cooking of a pizza test load for use during the cooking-energy efficiency and production capacity tests.

10.7.6 Set the rapid cook oven controls to the manufacturer's recommended setting for cooking the amount of chicken breasts, as determined in 10.6.3, comprising a chicken test load. Estimate a cook time for the chicken breasts.

NOTE 15—The rapid cook oven may allow for several different recipes or programs which will all cook the test chicken breasts to an adequate doneness. The researcher should choose the recipe or program that cooks the chicken breasts in the shortest amount of time and with the lowest energy consumption while maintaining the highest quality of the finished product. The manufacturer can be a valuable resource in optimizing this cooking process and should be consulted where possible.

10.7.7 Remove the amount of chicken breasts comprising a chicken test load, as determined in 10.6.3, and place them on the manufacturer's recommended cooking container. The chicken breasts must be spread open and must be placed so as to cover as much of the bottom surface area of the cooking container as possible without allowing any part of two adjacent chicken breasts to overlap. Place the cooking container in the center of the oven. Do not allow more than 1 minute to elapse from the time the chicken breasts are removed from the refrigerator until they are placed in the oven.

10.7.8 Allow the chicken breasts to cook for the duration of the estimated cook time and then remove the chicken breasts and the cooking container from the rapid cook oven.

10.7.9 Determine the final average temperature of the chicken test load (all the chicken breasts) by inserting a thermocouple probe into the thickest part of each chicken breast. Insert the probes into the side of the chicken breasts so that the probes are parallel with the bottom of the cooking container. Allow no more than 10 seconds from the time the chicken breasts are removed from the oven to the time all of the probes are inserted into all of the chicken breasts. Leave the probes in place and record and average the temperatures of all the probes every five seconds over a one minute period (for a total of 12 readings). The final average temperature of all the chicken breasts is the highest average temperature of all the probes during the one minute period. If the final average chicken test load temperature is not $170 \pm 3^{\circ}\text{F}$, adjust the cook time and repeat the cook time determination test as necessary to produce a $170 \pm 3^{\circ}\text{F}$ final temperature.

10.7.10 Record the determined cook time and the recipe or program for optimized cooking of a chicken test load for use during the cooking-energy efficiency and production capacity tests.

10.8 *Cooking-Energy Efficiency and Production Capacity:*

10.8.1 Turn the rapid cook oven on and allow it to achieve a ready-to-cook state. If the oven requires preheating in order to achieve a ready-to-cook state then allow the oven to idle for 60 min. after it is fully preheated.

10.8.2 The cooking-energy efficiency and production capacity tests are to be run a minimum of three times. Allow a minimum of 15 minutes between each test run. Additional test runs may be necessary to obtain the required precision for the reported test results (see Annex A1). The cooking-energy efficiency tests shall be performed in the following sequence, starting with pizza test loads and progressing to chicken test loads.

10.8.3 Set the rapid cook oven controls to the recipe or program for optimized cooking of a pizza test load as determined in 10.7. If the manufacturer recommends cooking parbaked pizza using a cooking surface or container that is separate from the oven deck, then weigh the recommended surface or container and record the weight.

10.8.4 Remove a pizza test load (a single pizza) from the refrigerator, weigh the uncooked pizza, record the weight and place the pizza directly on the manufacturer's recommended cooking surface or cooking container in the center of the oven. If the manufacturer does not recommend a separate cooking surface or cooking container for cooking parbaked pizza then place the pizza directly on the oven deck. Do not allow more than 1 minute to elapse from the time a pizza is removed from the refrigerator until it is placed in the oven. Close the rapid cook oven door and immediately start the program to initiate the cook cycle. Start monitoring time and energy immediately upon initiation of the cook cycle.

NOTE 16— It is recommended that a pizza peel be used to safely remove hot pizzas from inside the oven. A pizza peel consists of a flat metal or wood blade connected to a handle. Sized to lift a single pizza, the peel allows the operator to load and remove a pizza from the oven without having to touch the pizza or extend an arm into the oven.

10.8.5 When the programmed cook cycle is complete, or the pizza test load has been in the oven the same amount of time as the cook time determined in 10.7, open the oven door and remove the pizza. Close the oven door immediately after removing the pizza. Stop monitoring time and energy as soon as the oven has recovered to the ready-to-cook state. Determine the final pizza test load temperature as detailed in the cook time determination.

10.8.6 Remove any cheese that may stick to the thermocouple probes during temperature measurement and place the cheese back on the pizza. Weigh the cooked pizza and record the weight. Record the time and the energy.

10.8.7 Set the rapid cook oven controls to the recipe or program for optimized cooking of a chicken test load as determined in 10.7. Weigh the manufacturer's recommended cooking container and record the weight.

10.8.8 Remove a chicken test load from the refrigerator and place the chicken breasts on the cooking container as detailed in 10.7. Weigh the cooking container and chicken breast and immediately place the cooking container in the center of the oven. Do not allow more than 1 minute to elapse from the time the chicken test load is removed from the refrigerator until it is placed in the oven. Close the rapid cook oven door and immediately start the program to initiate the cook cycle. Start monitoring time and energy immediately upon initiation of the cook cycle. Record the total uncooked weight of the chicken test load.

10.8.9 When the programmed cook cycle is complete, or the chicken test load has been in the oven the same amount of time as the cook time determined in 10.7, open the oven door and remove the cooking container. Close the oven door immediately after removing the cooking container. Stop monitoring time and energy as soon as the oven has recovered to the ready-to-cook state. Determine the final chicken test load temperature as detailed in the cook time determination, 10.7.

10.8.10 Within 10 seconds of determining the final temperature, remove the thermocouple probes from the chicken breasts and immediately weigh the cooking container and chicken breast, including any broth that might be on the cooking container. Record the final temperature, the test time, the total cooked weight of the chicken test load, and the energy consumed during the test. Remove the chicken breasts from the cooking container, leaving any

broth on the cooking container and shaking off any excess moisture that may have condensed on the chicken breasts. Weigh and record the net weight of the chicken test load.

NOTE 17—The total cooked weight of the chicken breasts will be subtracted from the total uncooked weight of the chicken breasts in order to determine the amount of moisture evaporated during the test. It is crucial to include all of the moisture that is remaining on the pans when determining the total cooked weight, so that the evaporation will not be exaggerated.

NOTE 18—The net weight of the chicken breasts will be subtracted from the total uncooked weight of the chicken breasts in order to determine the product shrinkage. The net weight is representative of the final product or the quantity of product that would be available to be served.

10.8.11 In accordance with section 11.8, calculate and report the cooking-energy efficiency, cooking energy rate, electric energy rate (if applicable for gas rapid cook ovens), and production capacity for the pizza test loads and the cooking-energy efficiency, cooking energy rate, electric energy rate (if applicable for gas rapid cook ovens), production capacity, and product shrinkage for the chicken test loads. Follow the procedure in Annex A1 to determine whether more than three tests runs are required.

10.9 *Barreling Energy Performance:*

NOTE 19—Because a rapid cook oven typically cooks the food product based on a specific timed interval as opposed to a strictly thermostatic control loop, the oven will often compensate for the accumulated heat gained during barreling cooking by reducing the cooking energy rate during the timed cook cycle. As a thermostatically controlled oven heats up, the cook time becomes shorter and the cooking energy rate remains the same but as a rapid cook oven heats up, the cook time remains the same and the cooking energy rate decreases resulting in an increase in energy efficiency. The barreling energy performance test determines how much the cooking energy rate decreases during barreling by heating the oven substantially with a series of pizza test loads. This information can then be used to estimate the energy requirements of the oven in a heavy use application and could be used to calculate the cooking-energy efficiency that the oven would achieve during heavy continuous usage while cooking either pizza or chicken breasts.

10.9.1 The barreling energy performance test shall be run a minimum of three times. Allow a minimum of 30 minutes between each barreling test run. Additional test runs may be necessary to obtain the required precision for the reported test results (see Annex A1). Each barreling test is comprised of a series of eight single cooking-energy efficiency tests using pizza test loads. Start monitoring time and energy immediately upon initiation of the first cook cycle and stop monitoring time and energy as soon as the oven has recovered to the ready-to-cook state following removal of the last pizza test load. Allow no more than 15 sec. between each single test run for unloading and re-loading of the oven. Determine the final temperature of each pizza and weigh each cooked pizza. Record the temperatures, weights, time and energy for each single run as well as the time and energy for the entire barreling test.

10.9.2 Set the rapid cook oven controls to the recipe or program for optimized cooking of a pizza test load as determined in 10.7. If the manufacturer recommends cooking parbaked pizza using a cooking surface or container that is separate from the oven deck, then weigh the recommended surface or container and record the weight.

10.9.3 Remove a pizza test load (a single pizza) from the refrigerator, weigh the uncooked pizza, record the weight and place the pizza directly on the manufacturer's recommended cooking surface or cooking container in the center of the oven. If the manufacturer does not recommend a separate cooking surface or cooking container for cooking parbaked pizza then place the pizza directly on the oven deck. Do not allow more than 1 minute to elapse from the time a pizza is removed from the refrigerator until it is placed in the oven. Close the rapid cook oven door and immediately start the program to initiate the cook cycle. Start monitoring time and energy immediately upon initiation of the cook cycle.

NOTE 20— It is recommended that a pizza peel be used to safely remove hot pizzas from inside the oven. A pizza peel consists of a flat metal or wood blade connected to a handle. Sized to lift a single pizza, the peel allows the operator to load and remove a pizza from the oven without having to touch the pizza or extend an arm into the oven.

10.9.4 When the programmed cook cycle is complete, or the pizza test load has been in the oven the same amount of time as the cook time determined in 10.7, open the oven door and remove the pizza. Close the oven door immediately after removing the pizza. Determine the final pizza test load temperature as detailed in the cook time determination.

10.9.5 Remove any cheese that may stick to the thermocouple probes during temperature measurement and place the cheese back on the pizza. Weigh the cooked pizza and record the weight. Record the time and the energy.

10.9.6 Repeat 10.9.2 to 10.9.5 for the remaining 7 single runs in the barreling run test.

10.9.7 In accordance with section 11.8, calculate and report the cooking energy rate for each single pizza load test run during the barreling test. Follow the procedure in Annex A1 to determine whether more than three barreling test runs are required.

11. Calculation and Report

11.1 Test Rapid cook oven:

11.1.1 Summarize the physical and operating characteristics of the rapid cook oven. If needed, describe other design or operating characteristics that may facilitate interpretation of the test results.

11.2 Apparatus and Procedure:

11.2.1 Confirm that the testing apparatus conformed to all of the specifications in Section 6. Describe any deviations from those specifications.

11.2.2 For electric rapid cook ovens, report the voltage for each test.

11.2.3 For gas rapid cook ovens, report the higher heating value of the gas supplied to the rapid cook oven during *each* test.

11.3 Gas Energy Calculations:

11.3.1 For gas rapid cook ovens, add electric energy consumption to gas energy for all tests, with the exception of the energy input rate test (Section 10.2).

11.3.2 Calculate the energy consumed based on:

$$E_{gas} = V \times HV \quad (1)$$

where:

E_{gas} = energy consumed by the appliance

HV = higher heating value

= energy content of gas measured at standard conditions, Btu/ft³

V = actual volume of gas corrected for temperature and pressure at standard conditions, ft³

$$= V_{meas} \times T_{cf} \times P_{cf}$$

where:

V_{meas} = measured volume of gas, ft³

T_{cf} = temperature correction factor

$$= \frac{\text{absolute standard gas temperature } ^\circ\text{R}}{\text{absolute actual gas temperature } ^\circ\text{R}}$$

$$= \frac{\text{absolute standard gas temperature } ^\circ\text{R}}{[\text{gas temp } ^\circ\text{F} + 459.67] ^\circ\text{R}}$$

P_{cf} = pressure correction factor

$$= \frac{\text{absolute actual gas pressure psia}}{\text{absolute standard pressure psia}}$$

$$= \frac{\text{gas gage pressure psig} + \text{barometric pressure psia}}{\text{absolute standard pressure psia}}$$

NOTE 21—Absolute standard gas temperature and pressure used in this calculation should be the same values used for determining the higher heating value. PG&E standard conditions are 519.67 °R and 14.73 psia.

11.4 Energy Input Rate:

11.4.1 Report the manufacturer's nameplate energy input rate in Btu/h for a gas rapid cook oven and kW for an electric rapid cook oven.

11.4.2 For gas or electric rapid cook ovens, calculate and report the measured energy input rate (Btu/h or kW) based on the energy consumed by the rapid cook oven during the period of peak energy input according to the following relationship:

$$q_{input} = \frac{E \times 60}{t} \quad (2)$$

where:

- q_{input} = measured peak energy input rate, Btu/h or kW
 E = energy consumed during period of peak energy input, Btu or kWh
 t = period of peak energy input, min

11.5 Preheat Energy and Time:

11.5.1 Report the preheat energy consumption (Btu or kWh) and preheat time (min).

11.6 Idle Energy Rate:

11.6.1 Calculate and report the idle energy rate (Btu/h or kW) based on:

$$q_{idle\ rate} = \frac{E \times 60}{t} \quad (3)$$

where:

- $q_{idle\ rate}$ = idle energy rate, Btu/h or kW
 E = energy consumed during the test period, Btu or kWh
 t = test period, min

11.7 Pilot Energy Rate:

11.7.1 Calculate and report the pilot energy rate (Btu/h) based on:

$$q_{pilot\ rate} = \frac{E \times 60}{t} \quad (4)$$

where:

- $q_{pilot\ rate}$ = pilot energy rate, Btu/h
 E = energy consumed during the test period, Btu
 t = test period, min

11.8 *Cooking-Energy Efficiency, Cooking Energy Rate, Production Capacity and Product Shrinkage:*

11.8.1 Calculate the cooking-energy efficiency, $\eta_{\text{cook-pizza}}$, for pizza test load cooking tests based on:

$$\eta_{\text{cook-pizza}} = \frac{E_{\text{food}} + E_{\text{pan}}}{E_{\text{appliance}}} \times 100 \quad (5)$$

where:

$\eta_{\text{cook-pizza}}$ = pizza test load cooking-energy efficiency, %

E_{food} = energy into food, Btu

$$= (W_{\text{uncooked}} \times C_p (\text{Pizza}) \times (T_2 - T_1)) + ((W_{\text{uncooked}} - W_{\text{cooked}}) * H_{\text{fgt2}})$$

E_{pan} = energy into the manufacturer's recommended cooking surface or cooking container, Btu

$$= W_{\text{pan}} \times C_p (\text{Pan}) \times (T_2 - T_1)$$

W_{uncooked} = weight of pizza test load before it is cooked

W_{cooked} = weight of cooked pizza test load

W_{pan} = weight of the manufacturer's recommended cooking surface or cooking container

$C_p (\text{Pizza})$ = the specific heat of pizzas based on the average specified pizza

$$= 0.593 \text{ Btu/lb}\cdot^\circ\text{F}$$

$C_p (\text{Pan})$ = the specific heat of the manufacturer's recommended cooking surface or cooking container

H_{fgt2} = the heat of vaporization of water (Btu/lb) as found from a table of thermodynamic properties of water at saturation (see 1993 ASHRAE Handbook of Fundamentals, Chapter 6, Table 3).

$$= 970 \text{ Btu/lb}$$

T_2 = the average final temperature of the pizza test load

T_1 = the initial temperature of the pizza test load

$$= 40^\circ\text{F}$$

$E_{\text{appliance}}$ = energy into the appliance including electric energy consumed by a gas rapid cook oven, Btu

The conversion factor for electric energy is 3,413 Btu / kWh.

11.8.2 Calculate the cooking-energy efficiency, $\eta_{\text{cook-chicken}}$, for chicken test load cooking tests based on:

$$\eta_{\text{cook-chicken}} = \frac{E_{\text{food}} + E_{\text{pan}}}{E_{\text{appliance}}} \times 100 \quad (6)$$

where:

$\eta_{\text{cook-chicken}}$ = chicken test load cooking-energy efficiency, %

E_{food} = energy into food, Btu

$$= (W_{\text{uncooked}} \times C_p (\text{Chicken}) \times (T_2 - T_1)) + ((W_{\text{uncooked}} - W_{\text{cooked}}) * H_{\text{fgt2}})$$

E_{pan} = energy into the manufacturer's recommended cooking container, Btu

$$= W_{pan} \times C_p (Pan) \times (T_2 - T_1)$$

$W_{uncooked}$ = total weight of uncooked chicken test load

W_{cooked} = total weight of cooked chicken test load including juice

W_{pan} = weight of the manufacturer's recommended cooking container

$C_p (Chicken)$ = the specific heat of chicken breasts based on an average moisture content of 75%
= 0.800 Btu/lb•°F

$C_p (Pan)$ = the specific heat of the manufacturer's recommended cooking container

H_{fg2} = the heat of vaporization of water (Btu/lb) as found from a table of thermodynamic properties of water at saturation (see 1993 ASHRAE Handbook of Fundamentals, Chapter 6, Table 3).
= 970 Btu/lb

T_2 = the average final temperature of the chicken test load

T_1 = the initial temperature of the chicken test load
= 40°F

$E_{appliance}$ = energy into the appliance including electric energy consumed by a gas rapid cook oven, Btu

The conversion factor for electric energy is 3,413 Btu / kWh.

11.8.3 Calculate the cooking energy rate for pizza load tests based on:

$$q_{cook\ rat\ e-pizza} = \frac{E \times 60}{t} \quad (7)$$

where:

$q_{cook\ rate-pizza}$ = cooking energy rate for pizza load test, Btu/h or kW

E = energy consumed during pizza load cooking test, Btu or kWh

t = cooking test period, min

For gas appliances, report separately a gas cooking energy rate and an electric cooking energy rate.

11.8.4 Calculate the cooking energy rate for chicken load tests based on:

$$q_{cook\ rat\ e-chicken} = \frac{E \times 60}{t} \quad (8)$$

where:

$q_{cook\ rate-chicken}$ = cooking energy rate for chicken load test, Btu/h or kW

E = energy consumed during chicken load cooking test, Btu or kWh

t = cooking test period, min

For gas appliances, report separately a gas cooking energy rate and an electric cooking energy rate.

11.8.5 Calculate production capacity, PC_{pizza} (pizzas/h and lb/h), based on:

$$PC1_{pizza} = \frac{P_{num} \times 60}{t} \qquad PC2_{pizza} = \frac{W \times 60}{t} \qquad (9)$$

where:

$PC1_{pizza}$ = production capacity of the rapid cook oven cooking pizza, pizzas/h

$PC2_{pizza}$ = production capacity of the rapid cook oven cooking pizza, lb/h

P_{num} = number of pizzas required for a pizza test load
= 1 pizza

W = total weight of pizza cooked during pizza load test, lb

t = cooking test period, min

11.8.6 Calculate production capacity, $PC_{chicken}$ (lb/h), based on:

$$PC_{chicken} = \frac{W \times 60}{t} \qquad (10)$$

where:

$PC_{chicken}$ = production capacity of the rapid cook oven cooking chicken breasts, lb/h

W = total weight of chicken breasts cooked during chicken load test, lb

t = cooking test period, min

11.8.7 Calculate product shrinkage (%) during the chicken load test based on:

$$S = \frac{W_{raw} - W_{net}}{W_{raw}} \times 100 \qquad (11)$$

S = product shrinkage, %

W_{raw} = total weight of the uncooked chicken test load

W_{net} = final net weight of the cooked chicken test load

11.8.8 Calculate the cooking energy rate for each single pizza load test run during barreling and the total reduction in the cooking energy rate from the first pizza test load to the sixth.

$$q_{cook\ rate-pizza} = \frac{E \times 60}{t} \qquad (12)$$

where:

$q_{cook\ rate-pizza}$ = cooking energy rate for pizza load test, Btu/h or kW

E = energy consumed during pizza load cooking test, Btu or kWh

t = cooking test period, min

$q_{total\ rate\ reduction}$ = difference in cooking energy rates between the first and sixth pizza load tests, Btu/h or kW

For gas appliances, report separately a gas cooking energy rate and an electric cooking energy rate.

11.8.9 Report the cook time and the three run average value of the cooking-energy efficiency, cooking energy rate and production capacity for both the pizza load tests and the chicken load tests. Report the three run average value of the product shrinkage for the chicken load tests. Report the three run average value of the cooking energy rates for each pizza load test during the barreling test and the total reduction, or difference in cooking energy rates, between the first and sixth pizza load tests.

12. Precision and Bias

12.1 Precision

12.1.1 Repeatability (within laboratory, same operator and equipment)

12.1.1.1 For cooking-energy efficiency and production capacity results, the percent uncertainty in each result has been specified to be no greater than $\pm 10\%$ based on at least three test runs.

12.1.1.2 The repeatability of each reported parameter is being determined.

12.1.2 Reproducibility (multiple laboratories)

12.1.2.1 The interlaboratory precision of the procedure in this test method for measuring each reported parameter is being determined.

12.2 Bias

12.2.1 No statement can be made concerning the bias of the procedures in this test method because there are no accepted reference values for the parameters reported.

Standard Test Method for the Performance of Rapid cook ovens

KEYWORDS

test method

rapid cook oven

pizza oven

energy

performance

efficiency

production capacity

throughput

cooking-energy efficiency

ANNEX

(MANDATORY INFORMATION)

A1. PROCEDURE FOR DETERMINING THE UNCERTAINTY IN REPORTED TEST

RESULTS

Note A1: The procedure described below is based on the method for determining the confidence interval for the average of several test results discussed in Section 6.4.3, ASHRAE Guideline 2-1986(RA90). It should only be applied to test results that have been obtained within the tolerances prescribed in this method. (e.g. thermocouples calibrated, range was operating within 5% of rated input during the test run).

A1.1 For the Cooking-Energy Efficiency and Production Capacity procedures, results are reported for the cooking-energy efficiency (η_{cook}) and the production capacity (PC). For the Barreling Energy Performance procedure, the total reduction in the cooking energy rate from the first barreling test run to the sixth is reported ($q_{total\ rate\ reduction}$). Each reported result is the average of results from at least three test runs. In addition, the uncertainty in these averages is reported. For each cooking-energy efficiency test (pizza test load and chicken test load), the uncertainty of η_{cook} must be no greater than $\pm 10\%$ before η_{cook} for that test can be reported and the uncertainty of PC must also be no greater than $\pm 10\%$ before PC for that test can be reported. For the barreling test, the uncertainty of the total cooking energy rate reduction $q_{total\ rate\ reduction}$ must be no greater than $\pm 10\%$ before $q_{total\ rate\ reduction}$ for that test can be reported.

A1.2 The uncertainty in a reported result is a measure of its precision. If, for example, the η_{cook} is 40%, the uncertainty must not be larger than $\pm 4\%$. This means that the true η_{cook} is within the interval between 36% and 44%. This interval is determined at the 95% confidence level, which means that there is only a 1 in 20 chance that the true η_{cook} could be outside of this interval.

A1.3 Calculating the uncertainty not only guarantees the maximum uncertainty in the reported results, but also is used to determine how many test runs are needed to satisfy this requirement. The uncertainty is calculated from the standard deviation of three or more test results and a factor from Table A1, which depends on the number of test results used to calculate the average. The percent uncertainty is the ratio of the uncertainty to the average expressed as a percent.

A1.4 Procedure:

Note A2: See A1.5 for example of applying this procedure

A1.4.1 *Step 1* - Calculate the average and the standard deviation for the η_{cook} , PC , and $q_{total\ rate\ reduction}$ using the results of the first three test runs:

Note A3: The formulas below may be used to calculate the average and sample standard deviation. However, it is recommended that a calculator with statistical function be used. If one is used, be sure to use the sample standard deviation function. Using the population standard deviation function will result in an error in the uncertainty.

The formula for the average (3 test runs) is:

$$X_{a3} = (1/3) \times (X_1 + X_2 + X_3)$$

where:

X_{a3} - average of results for η_{cook} , PC , q_{total} rate reduction

X_1, X_2, X_3 - results for η_{cook} , PC , q_{total} rate reduction

The formula for the sample standard deviation (3 test runs) is:

$$S_3 = (1/\sqrt{2}) \times \sqrt{(A_3 - B_3)}$$

where:

S_3 - standard deviation of results for η_{cook} , PC , q_{total} rate reduction

$$A_3 = (X_1)^2 + (X_2)^2 + (X_3)^2$$

$$B_3 = (1/3) \times (X_1 + X_2 + X_3)^2$$

Note A4: The “A” quantity is the sum of the squares of each test result, while the “B” quantity is the square of the sum of all test results multiplied by a constant (1/3 in this case).

A1.4.2 Step 2 - Calculate the absolute uncertainty in the average for each parameter listed in Step 1. Multiply the standard deviation calculated in Step 1 by the Uncertainty Factor corresponding to three test results from Table A1.

The formula for the absolute uncertainty (3 test runs) is:

$$U_3 = C_3 \times S_3$$

$$U_3 = 2.48 \times S_3$$

where:

U_3 - absolute uncertainty in average for η_{cook} , PC , q_{total} rate reduction

C_3 - uncertainty factor for 3 test runs (Table A1)

Table A1

Test Results, n	Uncertainty Factor, Cn
3	2.48
4	1.59
5	1.24
6	1.05
7	0.92
8	0.84
9	0.77
10	0.72

A1.4.3 *Step 3* - Calculate the percent uncertainty in each parameter average using the averages from Step 1 and the absolute uncertainties from Step 2.

The formula for the percent uncertainty (3 test runs) is:

$$\%U_3 = (U_3/Xa_3) \times 100\%$$

where:

$\%U_3$ - percent uncertainty in average for η_{cook} , PC , $q_{total\ rate\ reduction}$

U_3 - absolute uncertainty in average for η_{cook} , PC , $q_{total\ rate\ reduction}$

Xa_3 - average η_{cook} , PC , $q_{total\ rate\ reduction}$

A1.4.4 *Step 4* - If the percent uncertainty, $\%U_3$, is not greater than $\pm 10\%$ for η_{cook} , PC , $q_{total\ rate\ reduction}$ then report the average for η_{cook} , PC , and $q_{total\ rate\ reduction}$ along with their corresponding absolute uncertainty, U_3 in the following format:

$$Xa_3 \pm U_3$$

If the percent uncertainty is greater than $\pm 10\%$ for η_{cook} , PC , or $q_{total\ rate\ reduction}$ then proceed to Step 5.

A1.4.5 *Step 5* - Run a fourth test for each η_{cook} , PC , or $q_{total\ rate\ reduction}$ which resulted in the percent uncertainty being greater than $\pm 10\%$.

A1.4.6 *Step 6* - When a fourth test is run for a given η_{cook} , calculate the average and standard deviation for η_{cook} and PC using a calculator or the following formulas:

The formula for the average (4 test runs) is:

$$X_{a4} = (1/4) \times (X_1 + X_2 + X_3 + X_4)$$

where:

X_{a4} - average of results for η_{cook} , PC , q_{total} rate reduction

X_1, X_2, X_3, X_4 - results for η_{cook} , PC , q_{total} rate reduction

The formula for the standard deviation (four test runs) is:

$$S_4 = (1/\sqrt{3}) \times \sqrt{(A_4 - B_4)}$$

where:

S_4 - standard deviation of results for η_{cook} , PC , q_{total} rate reduction (4 test runs)

$$A_4 = (X_1)^2 + (X_2)^2 + (X_3)^2 + (X_4)^2$$

$$B_4 = (1/4) \times (X_1 + X_2 + X_3 + X_4)^2$$

A1.4.7 *Step 7* - Calculate the absolute uncertainty in the average for each parameter listed in Step 1. Multiply the standard deviation calculated in Step 6 by the Uncertainty Factor for four test results from Table A1.

The formula for the absolute uncertainty (four test runs) is:

$$U_4 = C_4 \times S_4$$

$$U_4 = 1.59 \times S_4$$

where:

U_4 - absolute uncertainty in average for η_{cook} , PC , q_{total} rate reduction

C_4 - the uncertainty factor for 4 test runs (Table A1).

A1.4.8 *Step 8* - Calculate the percent uncertainty in the parameter averages using the averages from Step 6 and the absolute uncertainties from Step 7.

The formula for the percent uncertainty (4 test runs) is:

$$\%U_4 = (U_4/X_{a4}) \times 100\%$$

where:

$\%U_4$ - percent uncertainty in average for η_{cook} , PC , q_{total} rate reduction

U_4 - absolute uncertainty in average for η_{cook} , PC , q_{total} rate reduction

X_{a4} - average η_{cook} , PC , q_{total} rate reduction

A1.4.9 *Step 9* - If the percent uncertainty, $\%U_4$, is no greater than $\pm 10\%$ for η_{cook} , PC , or q_{total} rate reduction then report the average for η_{cook} , PC , and q_{total} rate reduction along with their corresponding absolute uncertainty, U_4 in the following format:

$$X_{a4} \pm U_4$$

If the percent uncertainty is greater than $\pm 10\%$ for η_{cook} , PC , or $q_{total\ rate\ reduction}$ proceed to Step 10.

A1.4.10 *Step 10* - The step required for five or more test runs are the same as those described above. More general formulas are listed below for calculating the average, standard deviation, absolute uncertainty and percent uncertainty.

The formula for the average (n test runs) is:

$$X_{a_n} = (1/n) \times (X_1 + X_2 + X_3 + X_4 + \dots + X_n)$$

where:

n - number of test runs

X_{a_n} - average of results for η_{cook} , PC , $q_{total\ rate\ reduction}$

$X_1, X_2, X_3, X_4, \dots, X_n$ - results for η_{cook} , PC , $q_{total\ rate\ reduction}$

The formula for the standard deviation (n test runs) is:

$$S_n = (1/\sqrt{n-1}) \times (\sqrt{A_n - B_n})$$

where:

S_n - standard deviation of results for η_{cook} , PC , $q_{total\ rate\ reduction}$ (n test runs)

$$A_n = (X_1)^2 + (X_2)^2 + (X_3)^2 + (X_4)^2 + \dots + (X_n)^2$$

$$B_n = (1/n) \times (X_1 + X_2 + X_3 + X_4 + \dots + X_n)^2$$

The formula for the absolute uncertainty (n test runs) is:

$$U_n = C_n \times S_n$$

where:

U_n - absolute uncertainty in average for η_{cook} , PC , $q_{total\ rate\ reduction}$

C_n - uncertainty factor for n test runs (Table A1).

The formula for the percent uncertainty (n test runs) is:

$$\%U_n = (U_n/X_{a_n}) \times 100\%$$

where:

$\%U_n$ - percent uncertainty in average for η_{cook} , PC , $q_{total\ rate\ reduction}$

When the specified uncertainty, $\%U_n$, is less than or equal to $\pm 10\%$; report the average for η_{cook} , PC , and $q_{total\ rate\ reduction}$ along with their corresponding absolute uncertainty, U_n in the following format:

$$X_{a_n} \pm U_n$$

Note A5: In the course of running these tests, the tester may compute a test result that deviates significantly from the other test results. It may be tempting to discard such a result in an attempt to meet the $\pm 10\%$ uncertainty requirement. This should be done only if there is some physical evidence that the test run from which that particular result was obtained was not performed according to the conditions specified in this method. For example, a thermocouple was out of calibration or the oven's input rate was not within 5% of the rated input. To be sure all

results were obtained under approximately the same conditions, it is good practice to monitor those test conditions specified in this method.

A1.5 Example of Determining Uncertainty in Average Test Result.

A1.5.1 Three test runs for the full-energy input rate cooking efficiency test yielded the following η_{cook} results:

Test	η_{cook}
Run #1	33.8%
Run #2	31.3%
Run #3	30.5%

A1.5.2 *Step 1* - Calculate the average and standard deviation of the three test results for the η_{cook} .

The average of the three test results:

$$X_{a3} = (1/3) \times (X_1 + X_2 + X_3)$$

$$X_{a3} = (1/3) \times (33.8 + 31.3 + 30.5)$$

$$X_{a3} = 31.9\%$$

The standard deviation of the three test results:

First calculate "A₃" and "B₃":

$$A_3 = (X_1)^2 + (X_2)^2 + (X_3)^2$$

$$A_3 = (33.8)^2 + (31.3)^2 + (30.5)^2$$

$$A_3 = 3,052$$

$$B_3 = (1/3) \times [(X_1 + X_2 + X_3)^2]$$

$$B_3 = (1/3) \times [(33.8 + 31.3 + 30.5)^2]$$

$$B_3 = 3,046$$

The new standard deviation for the η_{cook} is:

$$S_3 = (1/\sqrt{2}) \times \sqrt{(3052 - 3046)}$$

$$S_3 = 1.73\%$$

A1.5.3 *Step 2* - Calculate the uncertainty in average.

$$U_3 = 2.48 \times S_3$$

$$U_3 = 2.48 \times 1.73$$

$$U_3 = 4.29\%$$

A1.5.4 *Step 3* - Calculate percent uncertainty.

$$\%U_3 = (U_3/X_{a3}) \times 100\%$$

$$\%U_3 = (4.29/31.9) \times 100\%$$

$$\%U_3 = 13.5\%$$

A1.5.5 *Step 4* - Run a fourth test. Since the percent uncertainty for the η_{cook} is greater than $\pm 10\%$, the precision requirement has not been satisfied. An additional test is run in an attempt to reduce the uncertainty. The η_{cook} from the fourth test run was 31.8%.

A1.5.6 *Step 5* - Recalculate the average and standard deviation for the η_{cook} using the fourth test result:

The new average η_{cook} is:

$$X_{a4} = (1/4) \times (X_1 + X_2 + X_3 + X_4)$$

$$X_{a4} = (1/4) \times (33.8 + 31.3 + 30.5 + 31.8)$$

$$X_{a4} = 31.9\%$$

The new standard deviation:

First calculate “A₄” and “B₄”.

$$A_4 = (X_1)^2 + (X_2)^2 + (X_3)^2 + (X_4)^2$$

$$A_4 = (33.8)^2 + (31.3)^2 + (30.5)^2 + (31.8)^2$$

$$A_4 = 4,064$$

$$B_4 = (1/4) \times [(X_1 + X_2 + X_3 + X_4)^2]$$

$$B_4 = (1/4) \times [(33.8 + 31.3 + 30.5 + 31.8)^2]$$

$$B_4 = 4,058$$

The new standard deviation for the η_{cook} is:

$$S_4 = (1/\sqrt{3}) \times \sqrt{(4,064 - 4,058)}$$

$$S_4 = 1.41\%$$

A1.5.7 *Step 6* - Recalculate the absolute uncertainty using the new average and standard deviation.

$$U_4 = 1.59 \times S_4$$

$$U_4 = 1.59 \times 1.41$$

$$U_4 = 2.24\%$$

A1.5.8 *Step 7* - Recalculate the percent uncertainty.

$$\%U_4 = (U_4/X_{a4}) \times 100\%$$

$$\%U_4 = (2.24/31.9) \times 100\%$$

$$\%U_4 = 7\%$$

A1.5.9 *Step 8* - Since the percent uncertainty, %U₄, is less than ± 10 %; the average for the η_{cook} is reported along with its corresponding absolute uncertainty, U₄ as follows:

η_{cook} : $31.9 \pm 2.24\%$

The PC and its absolute uncertainty can be calculated and reported following the same steps, assuming the $\pm 10\%$ precision requirement has been met for the corresponding η_{cook} .

APPENDIX
(Nonmandatory Information)

Results Reporting Sheets

Manufacturer _____
Model _____
Serial # _____
Date _____
Test Reference Number (optional) _____

Section 11.1 Test Oven
Description of operational characteristics:

Physical Dimensions

Size of rapid cook oven : _____ H x _____ W x _____ D inches

Section 11.2 Apparatus
____ Check if testing apparatus conformed to specifications in section 6.

Deviations :

Section 11.4 Energy Input Rate

Test Voltage (V) _____
Gas Heating Value (Btu/ft³) _____
Heat Source (microwave, halogen, convection, etc) _____
Rated (Btu/h or kW) _____
Measured (Btu/h or kW) _____
Percent Difference between Measured and Rated (%) _____
Second Heat Source (if applicable) _____
Rated (Btu/h or kW) _____
Measured (Btu/h or kW) _____
Percent Difference between Measured and Rated (%) _____
Fan / Control Energy Rate (kW, gas ovens only) _____

Section 11.5 Preheat Energy and Time

Test Voltage (V) _____
Gas Heating Value (Btu/ft³) _____
Energy Consumption (Btu or kWh) _____
Time _____

Section 11.6 Idle Energy Rate

Test Voltage (V) _____
Gas Heating Value (Btu/ft³) _____
Idle Energy Rate (Btu/h or kW) _____

Section 11.7 Pilot Energy Rate

Gas Heating Value (Btu/ft³) _____
Pilot Energy Rate (Btu/h) _____

Section 11.8 Cooking-Energy Efficiency, Cooking Energy Rate, Production Capacity, and Product Shrinkage

Cook Time Determination for Pizza:

Cook time: _____ Min
Load Size (pizza/load): _____
Type of cooking container: _____

Single Load Pizza Test:

Test Voltage (V) _____
Gas Heating Value (Btu/ft³) _____
Cooking-Energy Efficiency (%) _____
Percent Uncertainty (%) _____
Cooking Energy Rate (Btu/h or kW) _____
Electric Energy Rate (kW, gas ovens only) _____
Energy into food - E_{food} (Btu) _____
Energy to Cooking Container - E_{pan} (Btu) _____
Energy into the appliance - $E_{appliance}$ (Btu) _____
Energy into the appliance - $E_{appliance}$ (Wh) _____
Production Capacity (lb/h) _____
Production Capacity (pizzas/h) _____

Cook Time Determination for Chicken Breasts:

Cook time: _____ Min
Load Size (chicken breasts/load): _____
Type of cooking container: _____

Single Load Chicken Breasts Test:

Test Voltage (V) _____
Gas Heating Value (Btu/ft³) _____
Cooking-Energy Efficiency (%) _____
Percent Uncertainty (%) _____
Cooking Energy Rate (Btu/h or kW) _____
Electric Energy Rate (kW, gas ovens only) _____
Energy into food - E_{food} (Btu) _____
Energy to Cooking Container - E_{pan} (Btu) _____
Energy into the appliance - $E_{appliance}$ (Btu) _____
Energy into the appliance - $E_{appliance}$ (Wh) _____
Production Capacity (lb/h) _____
Product Shrinkage (%) _____

Barreling Performance Test:

Test Voltage (V) _____
Gas Heating Value (Btu/ft³) _____
Cooking Energy Rate (Btu/h or kW) – Load # 1 _____
Cooking Energy Rate (Btu/h or kW) – Load # 2 _____
Cooking Energy Rate (Btu/h or kW) – Load # 3 _____
Cooking Energy Rate (Btu/h or kW) – Load # 4 _____
Cooking Energy Rate (Btu/h or kW) – Load # 5 _____
Cooking Energy Rate (Btu/h or kW) – Load # 6 _____
Total Reduction in Cooking Energy Rate (Btu/h or kW) _____

Appendix C

**PROCEDURE FOR DETERMINING THE MOISTURE CONTENT OF FOOD
PRODUCTS USING GRAVIMETRIC MOISTURE ANALYSIS**

DETERMINING THE MOISTURE CONTENT OF FOOD PRODUCTS USING GRAVIMETRIC MOISTURE ANALYSIS

Moisture content of food products can have a significant effect on the amount of energy required for cooking. It was imperative for researchers to be able to quickly and accurately determine whether a food product was within specifications before commencing testing. Moisture contents are also used in energy-to-food calculations. The moisture content of raw and cooked food can be determined using an air drying method and determining the gravimetric weight loss.

A 1 lb. sample of the test food is placed on a dry, aluminum sheet pan. The pan may be lined with baking paper to protect the sheet pan and facilitate clean-up. The sample is then thoroughly chopped, ground, or otherwise broken apart into 1/8-inch or smaller squares and spread the evenly over the surface of the sheet pan in order for all the moisture to evaporate during drying.

The sample is weighed and placed into a convection drying oven at a temperature of $220 \pm 5^{\circ}\text{F}$ for a minimum of 18 hours. The sample is weighed after drying to determine the weight loss. The moisture content of the sample is equal to the weight lost during drying. The percentage of moisture can be calculated as follows:

$$\text{Percent Moisture} = \frac{\textit{Weight Loss}}{\textit{Initial Weight of the Sample}} \times 100$$

Appendix D

**MEASUREMENT UNCERTAINTY ANALYSIS FOR
TEST INSTRUMENTATION**

Table D-1.
Measurement Uncertainty Analysis for Calculated Gas Energy.

Parameter	Symbol	Nominal Value	Nominal x 1.01 (Units)	New E _{gas} (Btu)	Sensitivity ^a (%)	Absolute Uncertainty (Units)	Percent Uncertainty ^b (%)	Sensitivity x % Uncertainty (%)	Parameter Sensitivity (squares, %)
Gas Volume	V _{meas}	121 cu ft	122.2	121,591	-1.00	1.21	1.0	-1.0	1.000
Gas Temp	T _{gas}	70 °F	70.7	120,228	0.13	1.00	1.4	0.2	0.036
Gas Pressure	P _{gas}	6.0 in. H2O	6.1	120,405	-0.01	0.50	8.3	-0.1	0.015
Barometric Pressure	P _{atm}	14.50 Psia	14.6	121,573	-0.99	0.10	0.7	-0.7	0.462
Heating Value	HV	1015.0 Btu/scf	1025.2	121,591	-1.00	2.00	0.2	-0.2	0.039
Gas Energy	E _{gas}	120,387 Btu					Total Measurement Uncertainty^c		1.25%
upper limit		121,887 Btu							
lower limit		118,888 Btu							

^a Sensitivity = % change in E_{gas} per 1% change in parameter [(E_{gas} - New E_{gas}) x 100% / E_{gas}]

^b Percent Uncertainty = percent change in parameter [Absolute Uncertainty x 100% / Nominal Value]

^c Total Measurement Uncertainty = Root Sum Squares

Table D-2.
Measurement Uncertainty Analysis for Calculated Energy Input Rate.

Parameter	Symbol	Nominal Value	Nominal x 1.01 (Units)	New E _{input rate} (Btu/h)	Sensitivity ^a (%)	Absolute Uncertainty (Units)	Percent Uncertainty ^b (%)	Sensitivity x % Uncertainty (%)	Parameter Sensitivity (squares, %)
Energy Measurement	E	120,000 Btu	121,200	121,200	-1.00	1,499	1.25	-1.25	1.560
Time	min	60 Min	61	118,812	0.99	0.08	0.13	0.13	0.017
Energy Input Rate	E _{input rate}	120,000 Btu/h						Total Measurement Uncertainty ^c	1.26%
upper limit		121,507 Btu/h							
lower limit		118,493 Btu/h							

^a Sensitivity = % change in E_{input rate} per 1% change in parameter [(E_{input rate} - New E_{input rate}) x 100% / E_{input rate}]

^b Percent Uncertainty = percent change in parameter [Absolute Uncertainty x 100% / Nominal Value]

^c Total Measurement Uncertainty = Root Sum Squares

Table D-3.
Measurement Uncertainty Analysis for Gas Rapid Cook Oven Pizza Cooking-Energy Efficiency.

Parameter	Symbol	Nominal Value	Nominal x 1.01 (Units)	New CEE	Sensitivity (%)	Absolute Uncertainty (Units)	Percent Uncertainty (%)	Sensitivity x % Uncertainty (%)	Parameter Sensitivity (squares, %)
Appliance Energy	$E_{\text{appliance}}$	1230.0 Btu	1242.3	15.3%	0.99	18.45	1.49	1.5	2.162
Initial Pizza Temp	T1	40 °F	40.4	15.4%	0.18	1.00	2.48	0.4	0.197
Final Pizza Temp	T2	195 °F	197.0	15.5%	-0.88	1.00	0.51	-0.4	0.197
Uncooked Pizza Weight	W_{uncooked}	1.43 lb	1.45	16.7%	-8.04	0.01	0.69	-5.5	30.762
Cooked Pizza Weight	W_{cooked}	1.38 lb	1.39	14.3%	7.04	0.01	0.72	5.1	25.667
Cp Pizza	Cp (C)	0.59 Btu/lb, °F	0.60	15.5%	-0.70	0.01	1.67	-1.2	1.349
Cooking-Energy Efficiency	$\eta_{\text{cook-pizza}}$	15.4%						Total Measurement Uncertainty	7.77%
*upper limit		16.6%							
*lower limit		14.2%							

^a Sensitivity = % change in $\eta_{\text{cook-pizza}}$ per 1% change in parameter [$(\eta_{\text{cook-pizza}} - \text{New } \eta_{\text{cook-pizza}}) \times 100\% / \eta_{\text{cook-pizza}}$]

^b Percent Uncertainty = percent change in parameter [Absolute Uncertainty x 100% / Nominal Value]

^c Total Measurement Uncertainty = Root Sum Squares

Table D-4.
Measurement Uncertainty Analysis for Gas Rapid Cook Oven Chicken Cooking-Energy Efficiency.

Parameter	Symbol	Nominal Value	Nominal x 1.01 (Units)	New CEE	Sensitivity (%)	Absolute Uncertainty (Units)	Percent Uncertainty (%)	Sensitivity x % Uncertainty (%)	Parameter Sensitivity (squares, %)
Appliance Energy	E _{appliance}	3.0 kBtu	3.0	12.9%	0.99	0.05	1.49	1.5	2.162
Initial Chicken Temp	T1	40 °F	40.4	13.0%	0.18	1.00	2.48	0.4	0.194
Final Chicken Temp	T2	170 °F	171.7	13.1%	-0.76	1.00	0.58	-0.4	0.194
Uncooked Chicken Weight	W _{uncooked}	1.50 lb	1.52	13.6%	-4.12	0.01	0.66	-2.7	7.392
Cooked Chicken Weight	W _{cooked}	1.33 lb	1.34	12.6%	3.30	0.01	0.74	2.5	6.030
Cp Chickens	Cp (C)	0.80 Btu/lb, °F	0.81	13.1%	-0.40	0.01	1.24	-0.5	0.244
Weight of Cooking Con- tainer	W _{pan}	1.35 lb	1.36	13.1%	-0.18	0.01	0.73	-0.1	0.017
Cp Cooking Container	Cp (Pan)	0.40 Btu/lb, °F	0.40	13.1%	-0.18	0.01	2.48	-0.4	0.197
Cooking-Energy Efficiency	$\eta_{cook-chicken}$	13.0%						Total Measurement Uncertainty	4.05%
*upper limit		13.6%							
*lower limit		12.5%							

^a Sensitivity = % change in $\eta_{cook-chicken}$ per 1% change in parameter [$(\eta_{cook-chicken} - \text{New } \eta_{cook-chicken}) \times 100\% / \eta_{cook-chicken}$]

^b Percent Uncertainty = percent change in parameter [Absolute Uncertainty x 100% / Nominal Value]

^c Total Measurement Uncertainty = Root Sum Squares

Table D-5.
Measurement Uncertainty Analysis for Electric Rapid Cook Oven Pizza Cooking-Energy Efficiency.

Parameter	Symbol	Nominal Value	Nominal x 1.01	New CEE	Sensitivity	Absolute Uncertainty	Percent Uncertainty	Sensitivity x % Uncertainty	
		(Units)		(%)	(Units)	(%)	(%)	(squares, %)	
Appliance Energy	E _{appliance}	820.0 Btu	828.2	22.9%	0.99	12.30	1.49	1.5	2.162
Initial Pizza Temp	T1	40 °F	40.4	23.1%	0.18	1.00	2.48	0.4	0.197
Final Pizza Temp	T2	195 °F	197.0	23.3%	-0.88	1.00	0.51	-0.4	0.197
Uncooked Pizza Weight	W _{uncooked}	1.43 lb	1.45	25.0%	-8.04	0.01	0.69	-5.5	30.762
Cooked Pizza Weight	W _{cooked}	1.38 lb	1.39	21.5%	7.04	0.01	0.72	5.1	25.667
Cp Pizza	Cp (C)	0.59 Btu/lb, °F	0.60	23.3%	-0.70	0.01	1.67	-1.2	1.349
Cooking-Energy Efficiency	<i>η_{cook-pizza}</i>	23.1 %					Total Measurement Uncertainty		7.77%
*upper limit		24.9 %							
*lower limit		21.3 %							

^a Sensitivity = % change in *η_{cook-pizza}* per 1% change in parameter [(*η_{cook-pizza}* - New *η_{cook-pizza}*) x 100% / *η_{cook-pizza}*]

^b Percent Uncertainty = percent change in parameter [Absolute Uncertainty x 100% / Nominal Value]

^c Total Measurement Uncertainty = Root Sum Squares

Table D-6.
Measurement Uncertainty Analysis for Electric Rapid Cook Oven Chicken Cooking-Energy Efficiency.

Parameter	Symbol	Nominal Value	Nominal x 1.01	New CEE	Sensitivity	Absolute Uncertainty	Percent Uncertainty	Sensitivity x % Uncertainty	
		(Units)		(%)	(Units)	(%)	(%)	(squares, %)	
Appliance Energy	E _{appliance}	2.0 kBtu	2.0	19.4%	0.99	0.03	1.49	1.5	2.162
Initial Chicken Temp	T1	40 °F	40.4	19.5%	0.18	1.00	2.48	0.4	0.194
Final Chicken Temp	T2	170 °F	171.7	19.7%	-0.76	1.00	0.58	-0.4	0.194
Uncooked Chicken Weight	W _{uncooked}	1.50 lb	1.52	20.4%	-4.12	0.01	0.66	-2.7	7.392
Cooked Chicken Weight	W _{cooked}	1.33 lb	1.34	18.9%	3.30	0.01	0.74	2.5	6.030
Cp Chickens	Cp (C)	0.80 Btu/lb, °F	0.81	19.6%	-0.40	0.01	1.24	-0.5	0.244
Weight of Cooking Container	W _{pan}	1.35 lb	1.36	19.6%	-0.18	0.01	0.73	-0.1	0.017
Cp Cooking Container	Cp (Pan)	0.40 Btu/lb, °F	0.40	19.6%	-0.18	0.01	2.48	-0.4	0.197
Cooking-Energy Efficiency	$\eta_{cook-chicken}$	19.6%					Total Measurement Uncertainty		4.05%
*upper limit		20.3%							
*lower limit		18.8%							

^a Sensitivity = % change in $\eta_{cook-chicken}$ per 1% change in parameter [$(\eta_{cook-chicken} - \text{New } \eta_{cook-chicken}) \times 100\% / \eta_{cook-chicken}$]

^b Percent Uncertainty = percent change in parameter [Absolute Uncertainty x 100% / Nominal Value]

^c Total Measurement Uncertainty = Root Sum Squares

Appendix E

COOKING-ENERGY EFFICIENCY DATA

Table E-1.
Specific Heat and Latent Heat.

Specific Heat (Btu/lb, °F)	
Chicken Breast	0.800
Test Pizza	0.593
Latent Heat (Btu/lb)	
Vaporization, Water	970

Table E-2.
Rapid Cook Oven A Pizza Single-Load Test Data.

Measured Values	Repetition #1	Repetition #2	Repetition #3
Total Energy (Wh)	180	180	180
Cook Time (min)	1.2	1.2	1.2
Initial Weight (lb)	1.463	1.463	1.431
Final Weight (lb)	1.397	1.397	1.361
Initial Temperature (°F)	40	40	40
Final Temperature (°F)	194.8	192.8	193.1
Calculated Values			
Sensible to Solids (Btu)	134	133	130
Latent - Water Vaporization (Btu)	64	64	68
Total Energy to Food (Btu)	198	197	198
Energy to Food (Btu/lb)	136	134	138
Total Energy to Oven (Btu)	614	614	614
Energy to Oven (Btu/lb)	420	420	429
Cooking-Energy Efficiency (%)	32.3	32.0	32.2
Cooking Energy Rate (kW)	9.0	9.0	9.0

Table E-3.
Rapid Cook Oven A Chicken Single-Load Test Data.

Measured Values	Repetition #1	Repetition #2	Repetition #3
Total Energy (Wh)	280	280	280
Cook Time (min)	1.6	1.6	1.6
Number of Breasts	6	6	6
Initial Weight (lb)	1.473	1.511	1.488
After-Cook Weight (lb)	1.335	1.362	1.342
Final Weight (lb)	1.159	1.173	1.158
Initial Temperature (°F)	40	40	40
Final Average Temperature (°F)	173.8	166.2	172.2
Calculated Values			
Sensible to Solids (Btu)	158	153	157
Latent- Water Vaporization (Btu)	137	148	145
Total Energy to Food (Btu)	295	301	303
Energy to Food (Btu/lb)	200	199	203
Total Energy to Oven (Btu)	956	956	956
Energy to Oven (Btu/lb)	649	632	642
Cooking-Energy Efficiency (%)	30.9	31.5	31.7
Cooking Energy Rate (kW)	10.6	10.6	10.6
Product Shrinkage (%)	21.3	22.4	22.2

Table E-4.
Rapid Cook Oven A Pizza Barreling Test Data.

Measured Values	Pizza #1	Pizza #2	Pizza #3
Total Energy (Wh)	180	180	160
Cook Time (min)	1.2	1.2	1.2
Initial Weight (lb)	1.438	1.436	1.443
Final Weight (lb)	1.372	1.375	1.378
Initial Temperature (°F)	40	40	40
Final Temperature (°F)	193.5	193.3	193.4
Calculated Values			
Sensible to Solids (Btu)	131	131	131
Latent - Water Vaporization (Btu)	65	60	64
Total Energy to Food (Btu)	196	190	195
Energy to Food (Btu/lb)	136	133	135
Total Energy to Oven (Btu)	614	614	546
Energy to Oven (Btu/lb)	427	428	378
Cooking-Energy Efficiency (%)	31.9	31.0	35.7
Cooking Energy Rate (kW)	9.0	9.0	8.0
Production Capacity (pizzas/h)	39.6	39.6	39.6
Production Capacity (lb/h)	57.1	57.1	57.1

Table E-4 (continued).
Rapid Cook Oven A Pizza Barreling Test Data.

Measured Values	Pizza #4	Pizza #5	Pizza #6
Electric Energy (Wh)	160	140	140
Cook Time (min)	1.2	1.2	1.2
Initial Weight (lb)	1.438	1.446	1.455
Final Weight (lb)	1.379	1.386	1.384
Initial Temperature (°F)	40	40	40
Final Temperature (°F)	194.2	195.2	190.3
Calculated Values			
Sensible to Solids (Btu)	131	133	130
Latent - Water Vaporization (Btu)	58	59	70
Total Energy to Food (Btu)	189	192	199
Energy to Food (Btu/lb)	132	133	137
Total Energy to Oven (Btu)	546	478	478
Energy to Oven (Btu/lb)	380	330	328
Cooking-Energy Efficiency (%)	34.7	40.2	41.7
Cooking Energy Rate (kW)	8.0	7.0	7.0
Production Rate (pizzas/h)	39.6	39.6	39.6
Production Rate (lb/h)	57.1	57.1	57.1

Table E-5.
Rapid Cook Oven B Pizza Single-Load Test Data.

Measured Values	Repetition #1	Repetition #2	Repetition #3
Total Energy (Wh)	300	300	300
Cook Time (min)	2.5	2.5	2.5
Initial Weight (lb)	1.412	1.416	1.422
Final Weight (lb)	1.359	1.368	1.368
Initial Temperature (°F)	40	40	40
Final Temperature (°F)	198.0	196.2	192.4
Calculated Values			
Sensible to Solids (Btu)	132	131	129
Latent - Water Vaporization (Btu)	51	47	52
Total Energy to Food (Btu)	184	178	181
Energy to Food (Btu/lb)	130	126	127
Total Energy to Oven (Btu)	1024	1024	1024
Energy to Oven (Btu/lb)	725	723	720
Cooking-Energy Efficiency (%)	17.9	17.4	17.7
Cooking Energy Rate (kW)	7.2	7.2	7.2

Table E-6.
Rapid Cook Oven B Chicken Single-Load Test Data.

Measured Values	Repetition #1	Repetition #2	Repetition #3
Total Energy (Wh)	820	840	840
Cook Time (min)	4.5	4.5	4.5
Number of Breasts	5	5	5
Initial Weight (lb)	1.494	1.536	1.525
After-Cook Weight (lb)	1.288	1.335	1.309
Final Weight (lb)	1.191	1.251	1.224
Initial Temperature (°F)	40	40	40
Final Average Temperature (°F)	170.3	169.4	172.6
Weight of Baking Dish (lb)	2.710	2.710	2.710
Initial Baking Dish Temperature (°F)	75	75	75
Final Baking Dish Temperature (°F)	450	450	450
Calculated Values			
Sensible to Solids (Btu)	156	159	162
Latent- Water Vaporization (Btu)	205	200	215
Total Energy to Food (Btu)	361	359	377
Energy to Food (Btu/lb)	242	234	247
Energy to Baking Dish (Btu)	203	203	203
Total Energy to Food and Dish (Btu)	564	562	580
Total Energy to Oven (Btu)	2799	2867	2867
Energy to Oven (Btu/lb)	1873	1866	1880
Cooking-Energy Efficiency (%)	12.9	12.5	13.1
Cooking-Load Energy Efficiency (%)	20.2	19.6	20.2
Cooking Energy Rate (kW)	10.9	11.2	11.2
Product Shrinkage (%)	20.3	18.6	19.7

Table E-7.
Rapid Cook Oven B Pizza Barreling Test Data.

Measured Values	Pizza #1	Pizza #2	Pizza #3
Total Energy (Wh)	300	300	240
Cook Time (min)	2.5	2.5	2.5
Initial Weight (lb)	1.410	1.437	1.440
Final Weight (lb)	1.362	1.385	1.393
Initial Temperature (°F)	40	40	40
Final Temperature (°F)	196.3	195.5	192.7
Calculated Values			
Sensible to Solids (Btu)	131	133	130
Latent - Water Vaporization (Btu)	47	51	46
Total Energy to Food (Btu)	178	184	176
Energy to Food (Btu/lb)	126	128	123
Total Energy to Oven (Btu)	1024	1024	819
Energy to Oven (Btu/lb)	726	713	569
Cooking-Energy Efficiency (%)	17.4	17.9	21.6
Cooking Energy Rate (kW)	7.2	7.2	5.8
Production Capacity (pizzas/hr)	21.7	21.7	21.7
Production Rate (lb/h)	31.0	31.0	31.0

Table E-7 (continued).
Rapid Cook Oven B Pizza Barreling Test Data.

Measured Values	Pizza #4	Pizza #5	Pizza #6
Electric Energy (Wh)	240	220	200
Cook Time (min)	2.5	2.5	2.5
Initial Weight (lb)	1.399	1.417	1.452
Final Weight (lb)	1.356	1.376	1.414
Initial Temperature (°F)	40	40	40
Final Temperature (°F)	193.5	191.0	190.7
Calculated Values			
Sensible to Solids (Btu)	127	127	130
Latent - Water Vaporization (Btu)	42	40	37
Total Energy to Food (Btu)	169	167	167
Energy to Food (Btu/lb)	121	118	115
Total Energy to Oven (Btu)	819	751	683
Energy to Oven (Btu/lb)	586	530	470
Cooking-Energy Efficiency (%)	20.7	22.3	24.5
Cooking Energy Rate (kW)	5.8	5.3	4.8
Production Capacity (pizzas/hr)	21.7	21.7	21.7
Production Rate (lb/h)	31.0	31.0	31.0

Table E-8.
Rapid Cook Oven A Cooking-Energy Efficiency Statistics.

	Pizza	Chicken
Replicate #1	32.3	30.9
Replicate #2	32.0	31.5
Replicate #3	32.2	31.7
Average	32.2	31.4
Standard Deviation	0.15	0.42
Absolute Uncertainty	0.36	1.0
Percent Uncertainty	1.1	3.3

Table E-9.
Rapid Cook Oven B Cooking-Energy Efficiency Statistics.

	Pizza	Chicken*
Replicate #1	17.9	20.2
Replicate #2	17.4	19.6
Replicate #3	17.7	20.2
Average	17.7	20.0
Standard Deviation	0.29	0.34
Absolute Uncertainty	0.73	0.83
Percent Uncertainty	4.1	4.2

* Load Efficiencies