Standard Test Method for Performance of Upright Overfired Broilers[1]

This standard is issued under the fixed designation F2237; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method evaluates the energy consumption and cooking performance of overfired broilers. The food service operator can use this evaluation to select an overfired broiler and understand its performance and energy consumption.

1.2 This test method is applicable to gas and electric upright overfired broilers having input rates greater than 60,000 Btu/h (gas overfired broilers) or 10kW (electric overfired broilers).

1.3 The overfired broiler can be evaluated with respect to the following (where applicable):

1.3.1 Energy input rate (see 10.2),

1.3.2 Temperature uniformity of the broiler cavity (see 10.3),

1.3.3 Preheat energy consumption and time (see 10.4),

1.3.4 Pilot energy rate (if applicable) (see 10.5),

1.3.5 Idle energy rate (see 10.6), and

1.3.6 Cooking energy efficiency and production capacity (see 10.7).

1.4 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A36/A36M Specification for Carbon Structural Steel

D3588 Practice for Calculating Heat Value, Compressibility Factor, and Relative Density of Gaseous Fuels

2.2 *AOAC Document:*

AOAC Official Action 950.46 Air Drying to Determine Moisture Content of Meat and Meat Products[3]

2.3 *ASHRAE Standard:*

ASHRAE Handbook of Fundamentals "Thermal and Related Properties of Food and Food Materials," Chapter 30, Table 1, 1989[4]

2.4 *ANSI Standard:*

ANSI Z83.11 Gas Food Service Equipment[5]

3. Terminology

3.1 *Definitions:*

3.1.1 *broiler cavity, n*—that portion of the overfired broiler in which food products are heated or cooked.

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 overfired broiler during the cooking event.

3.1.3 *cooking energy rate, n*—average rate of energy consumption (Btu/h or kW) during the cooking energy efficiency tests.

3.1.4 *grate, broiler grate, n*—the platform on which food is placed while cooking in an overfired broiler.

3.1.5 *idle energy rate, n*—the overfired broiler's rate of energy consumption (kW or Btu/h), when empty, required to maintain the broiler's operating temperature while not cooking.

3.1.6 *overfired broiler, n*—an appliance with a high temperature radiant heat source above a heavy duty, sliding grate for cooking food, characterized by an open front cooking cavity and having an input rate greater than 60 000 Btu/h or 10kW.

NOTE 1—The upright overfired broiler is distinguished from the salamander and the cheese melter by its heavy duty, stand-alone construction and high energy input rate (see Fig. 1).

[1] This test method is under the jurisdiction of ASTM Committee F26 on Food Service Equipment and is the direct responsibility of Subcommittee F26.06 on Productivity and Energy Protocol.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Association of Official Analytical Chemists, 1111 N. 19th Street, Arlington, VA 22209.

[4] Available from American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE), 1791 Tullie Circle, NE, Atlanta, GA 30329.

[5] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

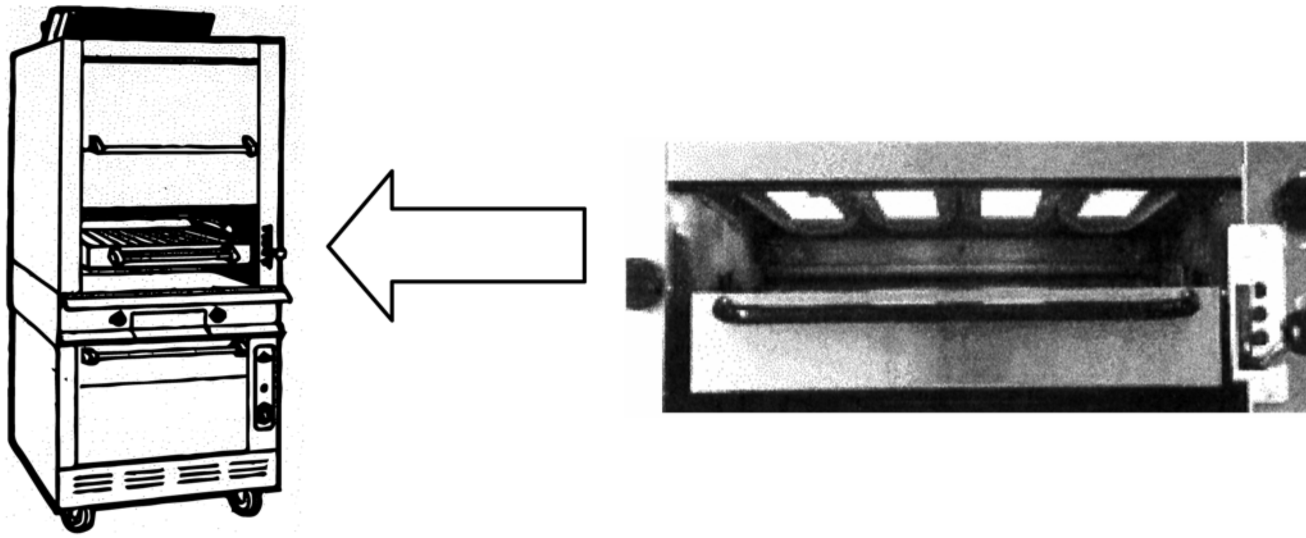

FIG. 1 Upright Overfired Broiler Construction

3.1.7 *pilot energy rate, n*—rate of energy consumption (Btu/h) by an overfired broiler's continuous pilot (if applicable).

3.1.8 *preheat energy, n*—amount of energy consumed (Btu or kWh), by the overfired broiler while preheating its cavity from ambient temperature to the calibrated control set point.

3.1.9 *preheat time, n*—time (min.) required for the overfired broiler cavity to preheat from ambient temperature to the calibrated control set point.

3.1.10 *production capacity, n*—maximum rate (lb/h) at which an overfired broiler can bring the specified food product to a specified "cooked" condition.

3.1.11 *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 The overfired broiler is connected to the appropriate metered energy source, and the energy input rate is determined to confirm that the appliance is operating within 5 % of the nameplate energy input rate.

4.2 The broiler grate is covered with 5-in. (127-mm) diameter steel disks and the overfired broiler's controls are set such that the broiling area does not exceed a maximum temperature of 800°F (315°C). The temperature uniformity of the broiling area is determined by monitoring thermocoupled steel disks placed on the broiler grate.

4.3 With the controls set such that the broiling area does not exceed 800°F (315°C), the amount of energy and time required to preheat the broiling area to 700°F (260°C) is determined.

4.4 The pilot energy rate is determined, when applicable, for gas overfired broilers.

4.5 Idle energy rate is determined while maintaining the broiler cavity at its operating temperature while not cooking.

4.6 With the controls set such that the broiling area does not exceed 800°F (315°C), the overfired broiler is used to cook 5-oz boneless, skinless, chicken breasts to an internal temperature of 170°F. Cooking energy efficiency is determined for light and heavy loading conditions.

4.7 Production capacity is determined for the heavy loading scenario.

5. Significance and Use

5.1 The energy input rate test is used to confirm that the overfired broiler is operating properly prior to further testing.

5.2 Temperature uniformity of the broiler cavity may be used by food service operators to select an overfired broiler with the desired temperature gradients.

5.3 Preheat energy and time can be useful to food service operators to manage energy demands and to know how quickly the overfired broiler can be ready for operation.

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

5.5 Cooking energy efficiency is a precise indicator of overfired broiler 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 an overfired broiler.

5.6 Production capacity can help an end user to better understand the production capabilities of an overfired broiler as it is used to cook a typical food product, helping with specification of 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 215 to 220°F (101 to 104°C), used to determine moisture content of both the raw and cooked food product.

6.5 *Data Acquisition System,* for measuring energy and temperatures, capable of multiple-temperature displays updating at least every 5 s.

6.6 *Gas Meter,* for measuring the gas consumption of an overfired broiler, 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 ft^3/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.

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

6.8 *Steel Disks,* composed of structural-grade carbon steel in accordance with Specification A36/A36M, free of rust or corrosion, 5-in. (127 mm) diameter, and ¼-in. (6.3-mm) thick. The disks shall be flat to within 0.010 in. (0.25 mm) over the diameter.

6.9 *Stop Watch,* with a 1-s resolution.

6.10 *Strain Gage Welder,* capable of welding thermocouples to steel.

6.11 *Temperature Sensor,* for measuring natural gas temperature in the range of 50 to 100°F (10 to 38°C) with an uncertainty of ±1°F (0.56°C).

6.12 *Thermocouple(s),* fiberglass insulated, 24 gage, Type K thermocouple wire, peened flat at the exposed ends and spot welded to the center of the steel disk surfaces with a strain gage welder.

6.13 *Thermocouple(s),* fiberglass insulated, 24 gage, Type K thermocouple wire, welded and calibrated, for use in determining the temperature of the chicken breasts.

6.14 *Watt-Hour Meter,* for measuring the electrical energy consumption of an overfired broiler, 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 *Aluminum Sheet Pans,* measuring 18 by 26 by 1 in. (457 by 660 by 25 mm), for use in packaging chicken breasts.

7.2 *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 ± 0.2 oz.

7.3 *Drip Rack,* sized to fit 18 by 26 by 1 in. (457 by 660 by 25 mm) aluminum sheet pans, for packaging chicken breasts.

7.4 *Fish Hooks,* size 1, for use in attaching thermocouples to chicken breasts.

7.5 *Plastic Wrap,* commercial grade, 18 in. (457 mm) wide, for use in packaging chicken breasts.

7.6 *Tongs,* commercial grade, metal construction, for handling chicken breasts.

8. Sampling and Test Units

8.1 *Overfired Broiler*—Select a representative production model for performance testing.

9. Preparation of Apparatus

9.1 Install the appliance according to the manufacturer's instructions under a canopy exhaust hood. Position the overfired broiler so that a minimum of 6 in. is maintained between the edge of the hood and the vertical plane of the front and sides of the appliance. In addition, both sides of the overfired broiler shall be a minimum of 3 ft from any side wall, side partition, or other operating appliance. The exhaust ventilation rate shall be 300 cfm per linear foot of active hood length. The associated heating or cooling system shall be capable of maintaining an ambient temperature of 75 ± 5°F within the testing environment when the exhaust ventilation system is operating.

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 overfired broiler 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 overfired broiler 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 ±2.5 % of the manufacturer's nameplate voltage.

9.3 For an electric overfired broiler, confirm (while the overfired broiler elements are energized) that the supply voltage is within ±2.5 % of the operating voltage specified by the manufacturer. Record the test voltage for each test.

NOTE 3—It is the intent of the test procedure herein to evaluate the performance of an overfired broiler at its rated gas pressure or electric voltage. If an electric unit is rated dual voltage (that is, designed to operate at either 208 or 240 V with no change in components), the voltage selected by the manufacturer or tester, or both, shall be reported. If an overfired broiler is designed to operate at two voltages without a change in the resistance of the heating elements, the performance of the unit (for example, the preheat time) may differ at the two voltages.

9.4 For a gas overfired broiler, adjust (during maximum energy input) the gas supply pressure downstream from the appliance's pressure regulator to within ±2.5 % of the operating manifold pressure specified by the manufacturer. Make adjustments to the appliance following the manufacturer's recommendations for optimizing combustion. Proper combustion may be verified by measuring air-free CO in accordance with ANSI Z83.11.

10. Procedure

10.1 *General:*

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

10.1.1.1 Higher heating value,

10.1.1.2 Standard gas pressure and temperature used to correct measured gas volume to standard conditions,

10.1.1.3 Measured gas temperature,

10.1.1.4 Measured gas pressure,

10.1.1.5 Barometric pressure,

10.1.1.6 Energy input rate during or immediately prior to test (for example, during the preheat for that day's testing), and

10.1.1.7 Ambient temperature.

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 overfired broiler under test. It is recommended that all testing be performed with gas having a higher heating value of 1000 to 1075 Btu/ft^3.

10.1.2 For gas overfired broilers, add electric energy consumption to gas energy for all tests, with the exception of the energy input rate test (see 10.2).

10.1.3 For electric overfired broilers, record the following for each test run:

10.1.3.1 Voltage while elements are energized,

10.1.3.2 Energy input rate during or immediately prior to test (for example, during the preheat for that day's testing), and

10.1.3.3 Ambient temperature.

10.1.4 For each test run, confirm that the peak input rate is within ±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 overfired broiler.

10.2 *Energy Input Rate:*

10.2.1 For gas overfired broilers, set the controls to achieve maximum input. Allow the unit to run for a period of 15 min, then monitor the time required for the overfired broiler to consume 10 ft^3 (0.28 m^3) of gas.

10.2.2 For electric overfired broilers, monitor the energy consumption for 15 min with the controls set to achieve maximum input.

10.2.3 Calculate and record the overfired broiler's energy input rate and compare the result to the rated nameplate input. Confirm that the measured input rate (Btu/h (kJ/h)) for a gas overfired broiler and kW for an electric overfired broiler) is within 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 overfired broiler, or supply another overfired broiler for testing.

NOTE 5—For gas overfired broilers, only the burner energy consumption is used to compare the calculated energy input rate with the rated gas input; any electrical energy use shall be calculated and recorded separately as the control energy rate.

10.3 *Temperature Uniformity:*

10.3.1 Using a strain gage welder, attach one thermocouple to the center of one side of each 5-in (127-mm) diameter, ¼-in (6.3-mm) thick steel disk. Add a strain relief to each thermocouple to facilitate handling of the disks.

10.3.2 Determine the number of disks required for the broiler under test as follows:

10.3.2.1 Measure the actual width and depth of the broiler grate.

10.3.2.2 Each column of disks (from front to back) shall have one disk for every 5¼ in. (133 mm) of grate depth.

10.3.2.3 Each row of disks (from side to side) shall have one disk for every 5¼ in. (133 mm) of grate width.

10.3.2.4 Record the number of disks used.

NOTE 6—This determination accounts for the differences between nominal broiler size and actual grate size. It is the intent of this test method to determine the temperature uniformity using a reasonable number of steel disks, while still allowing for space between disks.

10.3.3 Position the disks thermocoupled-side up on the broiler grate. Arrange the disks in a grid pattern and ensure that they are evenly spaced across the broiler grate (see Fig. 2).

10.3.4 Set the overfired broiler controls to achieve maximum input, then adjust the controls back so that the temperature of each disk does not exceed 800°F (412°C). Mark this position on the control knobs.

NOTE 7—The overfired broiler should be set such that the broiling temperature is as high as possible without exceeding 800°F (412°C).

NOTE 8—Be sure to stabilize the broiler for at least 60 min after any control adjustment.

10.3.5 Monitor the disk temperatures for a minimum of 60 min. Determine the average temperature for each disk.

10.4 *Preheat Energy Consumption and Time:*

10.4.1 Place one disk from 10.3.1 in the center of each linear foot (305 mm) of broiler grate, thermocouple side up.

10.4.2 Record the disk temperature(s) and the ambient kitchen temperature at the start of the test (each temperature shall be 75 ± 5°F (24 ± 2.8°C) at start of the test).

10.4.3 Set the overfired broiler controls to achieve maximum energy input.

10.4.4 Turn the broiler on and record the energy and time to preheat all sections of the overfired broiler jointly. Preheat is judged complete when the last of the disks reaches 700°F (357°C).

NOTE 9—Research at the Food Service Technology Center has determined that an overfired broiler is ready to cook when the broiler has

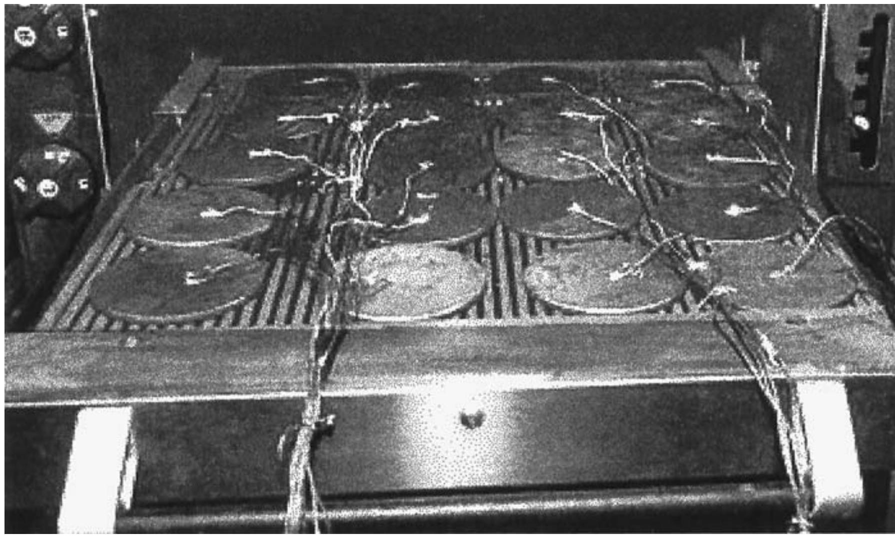

FIG. 2 Thermocouple Disk Placement

reached a temperature of 700°F.

10.5 *Pilot Energy Rate:*

10.5.1 For a gas overfired broiler with a standing pilot, set the gas valve at the "pilot" position and set the overfired broiler'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 h of pilot operation.

10.6 *Idle Energy Rate:*

10.6.1 Set the overfired broiler controls to the position determined in 10.3.4. Turn the overfired broiler on, preheat the broiler, and allow it to stabilize for 60 min.

10.6.2 After the 60-min stabilization period, monitor the energy consumption for an additional 2 h.

10.7 *Cooking Energy Efficiency:*

10.7.1 Cooking energy efficiency tests are performed for both heavy and light load scenarios. Determine the number of chicken breasts to be used in each test run as follows:

10.7.1.1 Each row (left to right) of chicken breasts placed on the grate for the heavy load test shall have one breast for each 4 in. of grate width. For example, an overfired broiler with a grate width of 25 in. would use six chicken breasts per row.

10.7.1.2 For heavy load test runs, there shall be one row of chicken breasts for each 4 in. of grate depth, minus the row nearest the front of the broiler. For example, an overfired broiler with a grate depth of 27 in. would use five rows of chicken breasts. This is determined by the following: 27 in. of grate depth equals six rows, minus the front row equals five rows.

NOTE 10—Research at the Food Service Technology Center has determined that the front row of an overfired broiler is much cooler than the rest of the broiler grate, due to design considerations and the open front configuration of the overfired broiler. As a result, food positioned on the front row will not cook to a proper doneness in the same time as food positioned elsewhere in the broiler. Therefore, the front row is omitted from the energy efficiency tests.

10.7.1.3 Each light load test run shall use five chicken breasts.

10.7.2 Thaw enough chicken breasts for a minimum of three heavy load and three light load test runs, based on the number of breasts determined in 10.7.1. Place thawed chicken breasts on drip racks and drain in a refrigerator for 1 h.

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 will affect the energy efficiency calculations and make test replication difficult.

NOTE 13—A minimum of three test runs is specified for each loading scenario, however, more test runs may be necessary if the results do not meet the uncertainty criteria specified in Annex A1.

10.7.3 Mark a sheet pan with a number for later identification. Weigh the sheet pan and record the weight. Place the number of chicken breasts required for the test run on the sheet pan. Weigh the pan with the chicken breasts to determine the weight of the chicken breasts. Determine the target weight range by multiplying the number of chicken breasts used by 0.3 ± 0.0125 lb. If the weight of the chicken breasts is not within the target weight range, thaw extra chicken breasts and substitute individual breasts as necessary to reach the target weight. Repeat 10.7.3 for each test run.

10.7.4 For heavy load test runs, use the number of rows determined in 10.7.1.2 to select an equal number of chicken breasts from each load to be monitored with thermocouples. For light load test runs, all five chicken breasts shall be monitored. With an appropriate length of fiberglass insulated, Type K thermocouple wire, expose approximately 3⁄16-in. of bare wire from one end and weld together. Insert thermocouple into the thickest part of each chicken breast, from the side and at an angle as close to horizontal as possible. The thermocouple wires may be secured to size 1 fish hooks, implanted in the chicken breasts near the thermocouple wire, to help prevent them from pulling out of position during the loading and turning sequences (see Figs. 3-5).

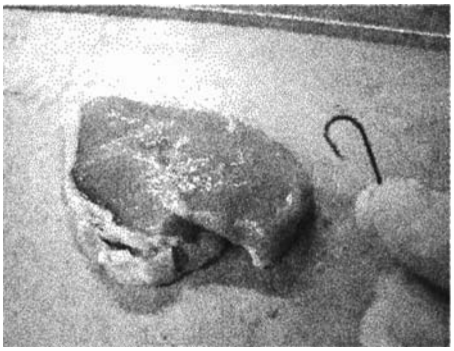

FIG. 3 Thermocouple Strain Relief

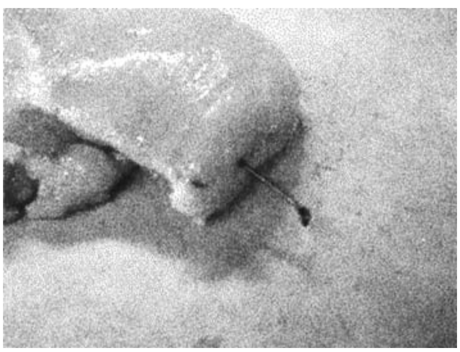

FIG. 4 Thermocouple Strain Relief

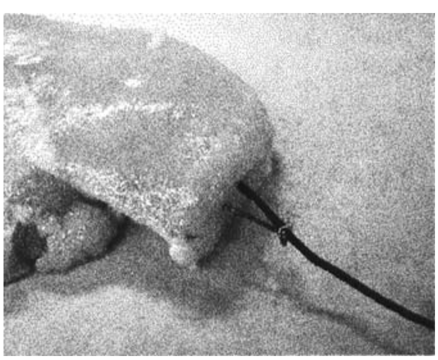

FIG. 5 Thermocouple Strain Relief

10.7.5 Cover the pans with cellophane (to inhibit moisture loss) and place in a refrigerator until they are stabilized at 37 ± 2°F. Do not store thawed chicken in the refrigerator for more than one week.

10.7.6 Set the overfired broiler controls to the position determined in 10.3.4. Turn the overfired broiler on, preheat the broiler, and allow it to stabilize for 60 min.

10.7.7 Remove the chicken breasts from the refrigerator. The initial average temperature of all the thermocoupled chicken breasts immediately prior to loading shall be 40 ± 2°F. Slide out the grate on the overfired broiler and coat with vegetable oil. For heavy load test runs, load the overfired broiler from left to right, and from back to front with the chicken breasts evenly spaced and no part of any adjacent breasts overlapping. Be certain to leave the first row at the front of the broiler empty, and to have one thermocoupled chicken breast in each row. Allow 15 s to load each five chicken breasts into the broiler (for example, a heavy load comprised of 30 chicken breasts is six groups of five chicken breasts = 6 times 15 s = 90 s load time). For light load test runs, place all five chicken breasts as near the center of the broiler as possible, allowing 15 s to load. When all the chicken breasts have been loaded, push the grate back into the overfired broiler and begin monitoring time and energy.

10.7.8 Cook the chicken for 4½ min on the first side, starting from the time the grate was pushed in and the test started. Slide out the grate and turn each chicken breast in the order they were loaded, in the same time period allowed for the loading of the broiler. Take extra precaution not to remove any of the thermocouples while turning, then slide in the grate and continue cooking.

NOTE 14—The 4½ min turn time is used as an approximate time period to allow equal cooking of the chicken breasts on each side. After the first test run, the turn time may be changed to reflect a period of one half the total cook time.

10.7.9 End the test when the average temperature of all thermocoupled chicken breasts reaches 170°F. Stop monitoring time and energy, slide out the broiler grate, and remove the chicken breasts to a pre-weighed aluminum sheet pan. Remove the thermocouples from the chicken breasts and immediately weigh the sheet pan and chicken breasts to determine the final cooked weight of the chicken breasts.

10.7.10 Once the chicken has been removed from the broiler and weighed, slide the grate back in and perform subsequent test runs by repeating 10.7.7 – 10.7.9. Allow the overfired broiler to idle for a period of 30 min between test runs. Follow the procedure in Annex A1 to determine if more than three test runs are required for each loading scenario.

10.7.11 In accordance with 11.9, calculate and report the cooking energy efficiency, cooking energy rate, electric energy rate (if applicable for gas overfired broilers), and production capacity.

11. Calculation and Report

11.1 *Test Overfired Broiler:*

11.1.1 Summarize the physical and operating characteristics of the overfired broiler. 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 overfired broilers, report the voltage for each test.

11.2.3 For gas overfired broilers, report the higher heating value of the gas supplied to the overfired broiler during each test.

11.3 *Gas Energy Calculations:*

11.3.1 For gas overfired broilers, add electric energy consumption to gas energy for all tests, with the exception of the energy input rate test (see 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/ft^3, and
V = actual volume of gas corrected for temperature and pressure at standard conditions, ft^3,
= $V_{meas} \times T_{cf} \times P_{cf}$

where:

V_{meas} = measured volume of gas, ft^3,
T_{cf} = temperature correction factor,
= *absolute standard gas temperature* °R / *absolute actual gas temperature* °R
= *absolute standard gas temperature* °R / [*gas temperature* °F + 459.67] °R
P_{cf} = pressure correction factor
= *absolute actual gas pressure* psia / *absolute standard pressure* psia
= *gas gage pressure* psig + *barometric pressure* psia / *absolute standard pressure* psia

NOTE 15—Absolute standard gas temperature and pressure used in this calculation should be the same values used for determining the higher heating value. Standard conditions using Practice D3588 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 gas overfired broilers and in kW for an electric overfired broiler.

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

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

where:

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

11.5 *Temperature Uniformity:*

11.5.1 Report the average temperature of each disk on a plan drawing of the broiler grate. Report the maximum deviation between the average temperature at any measurement location.

NOTE 16—A topographical temperature map of the broiling area may be used to enhance interpretation of the temperature uniformity test results.

11.5.2 Report the maximum temperature difference across the broiling area. The maximum difference is the highest average temperature minus the lowest average temperature for any disk.

11.6 *Preheat Energy and Time:*

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

11.6.2 Calculate and report the average preheat rate (°F/min) based on the preheat period. Also report the starting temperature of the broiling area.

11.7 *Pilot Energy Rate:*

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

$$q_{pilot} = \frac{E \times 60}{t} \qquad (3)$$

where:

q_{pilot} = pilot energy rate, Btu/h,
E = energy consumed during the test period, Btu, and
t = test period, min.

11.8 *Idle Energy Rate:*

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

$$q_{idle} = \frac{E \times 60}{t} \qquad (4)$$

where:

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

11.9 *Cooking Energy Efficiency, Cooking Energy Rate and Production Capacity:*

11.9.1 Calculate the cooking energy efficiency, η_{cook}, for cooking tests based on:

$$\eta_{cook} = \frac{E_{food}}{E_{appliance}} \qquad (5)$$

where:

η_{cook} = energy efficiency, %,
E_{food} = energy into food cooking, Btu, and
= $E_{sens} + E_{evap}$

where:

E_{sens} = quantity of heat added to chicken breasts, which causes their temperature to increase from the starting temperature to the final temperature of the cooked chicken breasts, Btu,
= $(W_i)(C_p)(T_f - T_i)$

where:

W_i = initial weight of chicken breasts, lb, and
C_p = specific heat of chicken breasts, Btu/lb, °F,
= 0.80
T_f = final internal temperature of the cooked chicken breasts, °F,
T_i = initial chicken breast temperature, °F, and
E_{evap} = latent heat (of vaporization) added to the chicken breasts, which causes some of the moisture contained in the chicken breasts to evaporate; the heat of vaporization cannot be perceived by a change in temperature and must be calculated after determining the amount of moisture lost from the cooked chicken breasts.
= $(W_i - W_f) \times H_v$

where:

W_i = initial weight of raw chicken breasts, lb,
W_f = final weight of cooked chicken breasts, lb,

H_v = heat of vaporization, Btu/lb,
= 970 Btu/lb at 212°F, and
$E_{appliance}$ = energy into broiler, Btu.

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

11.9.2 Calculate the cooking energy rate for cooking tests based on:

$$q_{cook} = \frac{E \times 60}{t} \quad (6)$$

where:

q_{cook} = cooking energy rate, Btu/h or kW,
E = energy consumed during cooking test, Btu or kWh, and
t = test time of cooking test, min.

11.9.3 Calculate the electric energy rate (if applicable, for gas overfired broilers) based on:

$$q_{electric} = \frac{E \times 60}{t} \quad (7)$$

where:

$q_{electric}$ = cooking energy rate, kW,
E = energy consumed during cooking test, kWh, and
t = test time of cooking test, min.

11.9.4 Calculate production capacity (lb/h) based on:

$$PC = \frac{W \times 60}{t} \quad (8)$$

where:

PC = production capacity of the overfired broiler, lb/h,
W = total weight of chicken breasts in the test load, lb, and
t = test time, min.

11.9.5 Report the three run average value of cook time, cooking energy efficiency, cooking energy rate, electric energy rate (if applicable) for heavy and light load tests. Report production capacity for the heavy load tests.

12. Precision and Bias

12.1 *Precision:*

12.1.1 *Repeatability* (within laboratory, same operator and equipment)

12.1.1.1 For the cooking energy efficiency and production rate results, the percent uncertainty in each result has been specified to be no greater than ±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.

13. Keywords

13.1 cooking energy efficiency; efficiency; energy; overfired broiler; performance; production capacity; test method

ANNEX

(Mandatory Information)

A1. PROCEDURE FOR DETERMINING THE UNCERTAINTY IN REPORTED TEST RESULTS

NOTE A1.1—This procedure is based on the ASHRAE method for determining the confidence interval for the average of several test results (ASHRAE Guideline 2-1986(RA90)). It should only be applied to test results that have been obtained within the tolerances prescribed in this method (for example, thermocouples calibrated, hamburger patty fat content within the 20 ± 2 % specification).

A1.1 For the cooking energy efficiency results, the uncertainty in the averages of at least three test runs is reported. For each loading scenario, the uncertainty of the cooking energy efficiency must be no greater than ±10 % before any of the parameters for that loading scenario can be reported.

A1.2 The uncertainty in a reported result is a measure of its precision. If, for example, the heavy-load efficiency for the appliance is 30 %, the uncertainty must not be greater than ±3 percentage points. Thus, the true heavy-load efficiency is between 27 and 33 %. This interval is determined at the 95 % confidence level, which means that there is only a 1 in 20 chance that the true heavy-load efficiency could be outside of this interval.

A1.3 Calculating the uncertainty not only guarantees the maximum uncertainty in the reported results, but is also 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 A1.1, which lists 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.

TABLE A1.1 Uncertainty Factors

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 *Procedure:*

NOTE A1.2—Section A1.5 shows how to apply this procedure.

A1.4.1 *Step 1*—Calculate the average and the standard deviation for the cooking-energy efficiency using the results of the first three test runs, as follows:

A1.4.1.1 The formula for the average (three test runs) is as follows:

$$Xa_3 = \left(\frac{1}{3}\right) \times (X_1 + X_2 + X_3) \tag{A1.1}$$

where:

Xa_3 = average of results for three test runs, and
X_1, X_2, X_3 = results for each test run.

A1.4.1.2 The formula for the sample standard deviation (three test runs) is as follows:

$$S_3 = \left(1/\sqrt{2}\right) \times \sqrt{(A_3 - B_3)} \tag{A1.2}$$

where:

S_3 = standard deviation of results for three test runs,
A_3 = $(X_1)^2 + (X_2)^2 + (X_3)^2$, and
B_3 = $(⅓) \times (X_1 + X_2 + X_3)^2$.

NOTE A1.3—The formulas may be used to calculate the average and sample standard deviation. However, a calculator with statistical function is recommended, in which case be sure to use the sample standard deviation function. The population standard deviation function will result in an error in the uncertainty.

NOTE A1.4—The "A" quantity is the sum of the squares of each test result, and the "B" quantity is the square of the sum of all test results multiplied by a constant (⅓ in this case).

A1.4.2 *Step 2*—Calculate the absolute uncertainty in the average for the cooking energy efficiency. Multiply the standard deviation calculated in Step 1 by the Uncertainty Factor corresponding to three test results from Table A1.1.

A1.4.2.1 The formula for the absolute uncertainty (three test runs) is as follows:

$$U_3 = C_3 \times S_3 \tag{A1.3}$$

$$U_3 = 2.48 \times S_3$$

where:

U_3 = absolute uncertainty in average for three test runs, and
C_3 = uncertainty factor for three test runs (see Table A1.1).

A1.4.3 *Step 3*—Calculate the percent uncertainty in the average cooking energy efficiency using the average from Step 1 and the absolute uncertainty from Step 2.

A1.4.3.1 The formula for the percent uncertainty (three test runs) is as follows:

$$\%U_3 = (U_3/Xa_3) \times 100\,\% \tag{A1.4}$$

where:

$\%U_3$ = percent uncertainty in average for three test runs,
U_3 = absolute uncertainty in average for three test runs, and
Xa_3 = average of three test runs.

A1.4.4 If the percent uncertainty, $\%U_3$, is not greater than ±10 % for the cooking-energy efficiency, report the average along with its corresponding absolute uncertainty, U_3, in the following format:

$$Xa_3 \pm U_3$$

If the percent uncertainty is greater than ± 10 % for the cooking energy efficiency, proceed to Step 5.

A1.4.5 *Step 5*—Run a fourth test for each loading scenario whose percent uncertainty was greater than ±10 %.

A1.4.6 *Step 6*—When a fourth test is run for a given loading scenario, calculate the average and standard deviation for test results using a calculator or the following formulas:

A1.4.6.1 The formula for the average (four test runs) is as follows:

$$Xa_4 = \left(\frac{1}{4}\right) \times (X_1 + X_2 + X_3 + X_4) \tag{A1.5}$$

where:

Xa_4 = average of results for four test runs, and
X_1, X_2, X_3, X_4 = results for each test run.

A1.4.6.2 The formula for the standard deviation (four test runs) is as follows:

$$S_4 = \left(1/\sqrt{3}\right) \times \sqrt{(A_4 - B_4)} \tag{A1.6}$$

where:

S_4 = standard deviation of results for four test runs,
A_4 = $(X_1)^2 + (X_2)^2 + (X_3)^2 + (X_4)^2$, and
B_4 = $(¼) \times (X_1 + X_2 + X_3 + X_4)^2$.

A1.4.7 *Step 7*—Calculate the absolute uncertainty in the average cooking energy efficiency. Multiply the standard deviation calculated in Step 6 by the Uncertainty Factor for four test results from Table A1.1.

A1.4.7.1 The formula for the absolute uncertainty (four test runs) is as follows:

$$U_4 = C_4 \times S_4 \tag{A1.7}$$

$$U_4 = 1.59 \times S_4$$

where:

U_4 = absolute uncertainty in average for four test runs, and
C_4 = the uncertainty factor for four test runs (see Table A1.1).

A1.4.8 *Step 8*—Calculate the percent uncertainty in the average cooking energy efficiency using the average from Step 6 and the absolute uncertainty from Step 7.

A1.4.8.1 The formula for the percent uncertainty (four test runs) is as follows:

$$\%U_4 = (U_4/Xa_4) \times 100\,\% \tag{A1.8}$$

where:

$\%U_4$ = percent uncertainty in average for four test runs,

U_4 = absolute uncertainty in average for four test runs, and
Xa_4 = average of four test runs.

A1.4.9 *Step 9*—If the percent uncertainty, $\%U_4$, is not greater than ±10 % for the cooking energy efficiency, report the average along with its corresponding absolute uncertainty, U_4, in the following format:

$$Xa_4 \pm U_4$$

If the percent uncertainty is greater than ±10 % for the cooking energy efficiency, proceed to Step 10.

A1.4.10 *Step 10*—The steps 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.

A1.4.10.1 The formula for the average (n test runs) is as follows:

$$Xa_n = \left(\frac{1}{n}\right) \times (X_1 + X_2 + X_3 + X_4 + \ldots + X_n) \quad \text{(A1.9)}$$

where:

n = number of test runs,
Xa_n = average of results n test runs, and
$X_1, X_1, X_2, X_3, X_4, \ldots X_n$ = results for each test run.

A1.4.10.2 The formula for the standard deviation (n test runs) is as follows:

$$S_n = \left(1/\sqrt{(n-1)}\right) \times \left(\sqrt{(A_n - B_n)}\right) \quad \text{(A1.10)}$$

where:

S_n = standard deviation of results for n test runs,
A_n = $(X_1)^2 + (X_2)^2 + (X_3)^2 + (X_4)^2 + \ldots + (X_n)^2$, and
B_n = $(1/n) \times (X_1 + X_2 + X_3 + X_4 + \ldots + X_n)^2$.

A1.4.10.3 The formula for the absolute uncertainty (n test runs) is as follows:

$$U_n = C_n \times S_n \quad \text{(A1.11)}$$

where:

U_n = absolute uncertainty in average for n test runs, and
C_n = uncertainty factor for n test runs (see Table A1.1).

A1.4.10.4 The formula for the percent uncertainty (n test runs) is as follows:

$$\%U_n = (U_n/Xa_n) \times 100\,\% \quad \text{(A1.12)}$$

where:

$\%U_n$ = percent uncertainty in average for n test runs,
U_n = absolute uncertainty in average for n test runs, and
Xa_n = average of n test runs.

When the percent uncertainty, $\%U_n$, is less than or equal to ±10 % for the cooking energy efficiency, report the average along with its corresponding absolute uncertainty, U_n, in the following format:

$$Xa_n \pm U_n$$

NOTE A1.5—The researcher may compute a test result that deviates significantly from the other test results. Such a result should be discarded only if there is some physical evidence that the test run was not performed according to the conditions specified in this method. For example, a thermocouple was out of calibration or the food product was not within specification. To assure that all results are 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 heavy-load cooking scenario yielded the following cooking energy efficiency results:

Test	Cooking Energy Efficiency
Run #1	33.8 %
Run #2	34.1 %
Run #3	31.0 %

A1.5.2 *Step 1*—Calculate the average and standard deviation of the three test results for the cooking energy efficiency.

A1.5.2.1 The average of the three test results is as follows:

$$Xa_3 = \left(\frac{1}{3}\right) \times (X_1 + X_2 + X_3) \quad \text{(A1.13)}$$

$$Xa_3 = \left(\frac{1}{3}\right) \times (33.8 + 34.1 + 31.0)$$

$$Xa_3 = 33.0\,\%$$

A1.5.2.2 The standard deviation of the three test results is as follows. First calculate "A_3" and "B_3:"

$$A_3 = (X_1)^2 + (X_2)^2 + (X_3)^2 \quad \text{(A1.14)}$$

$$A_3 = (33.8)^2 + (34.1)^2 + (31.0)^2$$

$$A_3 = 3\,266$$

$$B_3 = \left(\frac{1}{3}\right) \times [(X_1 + X_2 + X_3)^2]$$

$$B_3 = \left(\frac{1}{3}\right) \times [(33.8 + 34.1 + 31.0)^2]$$

$$B_3 = 3\,260$$

A1.5.2.3 The new standard deviation for the cooking energy efficiency is as follows:

$$S_3 = \left(\frac{1}{\sqrt{2}}\right) \times \sqrt{(3\,266 - 3\,260)}, \quad \text{(A1.15)}$$

$$S_3 = 1.71\,\%$$

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

$$U_3 = 2.48 \times S_3 \quad \text{(A1.16)}$$

$$U_3 = 2.48 \times 1.71$$

$$U_3 = 4.24\,\%$$

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

$$\%U_3 = \left(\frac{U_3}{Xa_3}\right) \times 100\,\%, \quad \text{(A1.17)}$$

$$\%U_3 = \left(\frac{4.24}{33.0}\right) \times 100\,\%$$

$$\%U_3 = 12.9\,\%$$

A1.5.5 *Step 4*—Run a fourth test. Since the percent uncertainty for the cooking energy efficiency is greater than ±10 %, the precision requirement has not been satisfied. An additional test is run in an attempt to reduce the uncertainty. The cooking energy efficiency from the fourth test run was 32.5 %.

A1.5.6 *Step 5*—Recalculate the average and standard deviation for the cooking energy efficiency using the fourth test result:

A1.5.6.1 The new average cooking energy efficiency is as follows:

$$Xa_4 = \left(\frac{1}{4}\right) \times (X_1 + X_2 + X_3 + X_4) \quad \text{(A1.18)}$$

$$Xa_4 = \left(\frac{1}{4}\right) \times (33.8 + 34.1 + 31.0 + 32.5)$$

$$Xa_4 = 32.9\,\%$$

A1.5.6.2 The new standard deviation is as follows. First calculate "A_4" and "B_4:"

$$A_4 = (X_1)^2 + (X_2)^2 + (X_3)^2 + (X_4)^2 \quad \text{(A1.19)}$$

$$A_4 = (33.8)^2 + (34.1)^2 + (31.0)^2 + (32.5)^2$$

$$A_4 = 4\,323$$

$$B_4 = \left(\frac{1}{4}\right) \times [(X_1 + X_2 + X_3 + X_4)^2]$$

$$B_4 = \left(\frac{1}{4}\right) \times [(33.8 + 34.1 + 31.0 + 32.5)^2]$$

$$B_4 = 4\,316$$

A1.5.6.3 The new standard deviation for the cooking energy efficiency is as follows:

$$S_4 = \left(\frac{1}{\sqrt{3}}\right) \times \sqrt{(4\,323 - 4\,316)} \quad \text{(A1.20)}$$

$$S_4 = 1.42\,\%$$

A1.5.7 *Step 6*—Recalculate the absolute uncertainty using the new standard deviation and uncertainty factor.

$$U_4 = 1.59 \times S_4 \quad \text{(A1.21)}$$

$$U_4 = 1.59 \times 1.42$$

$$U_4 = 2.25\,\%$$

A1.5.8 *Step 7*—Recalculate the percent uncertainty using the new average.

$$\%U_4 = \left(\frac{U_4}{Xa_4}\right) \times 100\,\%, \quad \text{(A1.22)}$$

$$\%U_4 = \left(\frac{2.25}{32.9}\right) \times 100\,\%,$$

$$\%U_4 = 6.8\,\%$$

A1.5.9 *Step 8*—Since the percent uncertainty, $\%U_4$, is less than ±10 %; the average for the cooking energy efficiency is reported along with its corresponding absolute uncertainty, U_4 as follows:

$$\text{cooking energy efficiency: } 32.9 \pm 2.25\,\% \quad \text{(A1.23)}$$

APPENDIX

(Nonmandatory Information)

X1. RESULTS REPORTING SHEETS

Manufacturer ______________________
Model ______________________
Date ______________________
Test Reference Number (optional) ______________________

Test Overfired Broiler

Description of operational characteristics: ______________________

Apparatus

____ Check if testing apparatus conformed to specifications in Section 6.
Deviations

Energy Input Rate

Test Voltage (V) ______
Gas Heating Value (Btu/ft^3 (kJ/m^3)) ______
Measured (Btu/h (kJ/h) or kW) ______
Rated (Btu/h (kJ/h) or kW) ______
Percent Difference between Measured and Rated (%) ______

Temperature Distribution

Maximum temperature difference across broiling area (°F (°C)): ______

Preheat Energy and Time

Test Voltage (V) ______
Gas Heating Value (Btu/ft^3 (kJ/m^3)) ______
Starting Temperature (°F (°C)) ______
Energy Consumption (Btu (kJ/h) or kWh) ______
Duration (min) ______
Preheat Rate (°F/min (°C/min)) ______

Pilot Energy Rate (if applicable)

Gas Heating Value (Btu/ft^3 (kJ/m^3)) ______
Pilot Energy Rate (Btu/h (kJ/h) or kW) ______

Idle Energy Rate

Test Voltage (V) ______
Gas Heating Value (Btu/ft^3 (kJ/m^3)) ______
Cooking Energy Rate (Btu/h (kJ/h) or kW) ______
Electric Energy Rate (kW, gas underfired broilers only) ______

Cooking Energy Efficiency

Heavy Load:

Test Voltage (V) ______
Gas Heating Value (Btu/ft^3 (kJ/m^3)) ______
Cooking Time (min) ______
Production Capacity (lb/h (kg/h)) ______
Cooking Energy Rate (Btu/h (kJ/h) or kW) ______
Electric Energy Rate, if applicable (kW) ______
Energy to Food (Btu/lb (kJ/kg)) ______
Energy per Pound of Food Cooked (Btu/lb (kJ/kg) or Wh/lb (Wh/kg)) ______
Cooking Energy Efficiency (%) ______

Light Load:

Test Voltage (V) ______
Gas Heating Value (Btu/ft^3 (kJ/m^3)) ______
Cooking Time (min) ______
Production Rate (lb/h (kg/h)) ______
Cooking Energy Rate (Btu/h (kJ/h) or kW) ______
Electric Energy Rate, if applicable (kW) ______
Energy to Food (Btu/lb (kJ/kg)) ______
Energy per Pound of Food Cooked (Btu/lb (kJ/kg) or Wh/lb (Wh/kg)) ______
Cooking Energy Efficiency (%) ______