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An American National Standard

Standard Test Method for Performance of Convection Ovens[1]

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1. Scope

1.1 This test method covers the energy consumption and cooking performance evaluation of convection ovens. The results of applying it can be used by the food service operator to select a convection oven and to understand its energy consumption.

1.2 This test method applies to general purpose, full-size, and half-size convection ovens used primarily for baking food products. It is not applicable to ovens used primarily for slow cooking and holding food product, to large roll-in rack-type ovens, or to ovens designed specifically to cook only one food product (for example, specialty ovens).

1.3 This test method is intended to be applied to convection ovens operated close to rated input in the dry heating mode, with the circulating fan operating at its maximum speed and without any injection of moisture into the oven cavity.

1.4 The oven's energy consumption and cooking performance are evaluated in this test method specifically with respect to the following:

1.4.1 Thermostat calibration (10.2),

1.4.2 Energy input rate and preheat energy consumption and time (10.3),

1.4.3 Pilot energy rate (if applicable) (10.4),

1.4.4 Idle energy rate (10.5),

1.4.5 Cooking energy efficiency and production capacity (10.6),

1.4.6 Cooking uniformity (10.7), and

1.4.7 White sheet cake browning (10.8).

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

1.6 *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:*

D 3588 Practice for Calculating Heat Value, Compressibility Factor, and Relative Density of Gaseous Fuels[2]

2.2 *ASHRAE Documents:*[3]

1989 ASHRAE Handbook of Fundamentals, Chapter 6, Table 2—Thermodynamic Properties of Water at Saturation

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

3. Terminology

3.1 *Definitions:*

3.1.1 *average preheat rate*—rate (°F/min) at which cavity temperature is heated from ambient temperature to the oven's thermostat set point.

3.1.2 *convection oven*—an appliance for cooking food by forcing hot air over the surface of the food using a fan in a closed cavity.

3.1.3 *cook time*—time required to cook potatoes during a cooking energy efficiency test.

3.1.4 *cooking energy*—energy consumed (kBtu or kWh) by the oven as it cooks potatoes during heavy-, medium-, or light-load cooking energy efficiency tests.

3.1.5 *cooking energy efficiency*—the ratio of the quantity of energy absorbed by the food product to the quantity of energy input to the oven during a cooking energy efficiency test expressed as a percent.

3.1.6 *cooking energy rate*—average rate of the oven's energy consumption (kBtu/h or kW) during a cooking energy efficiency test.

3.1.7 *fan and control energy rate*—the rate of energy consumption (kW and kBtu/h) by an oven's controls and fan motor.

3.1.8 *heavy load*—load (lb) during a cooking energy efficiency test consisting of approximately 14.5 lb (6.6 kg) of potatoes on each of five sheet pans spaced evenly in a full-size oven (7.25 lb (3.29 kg) of potatoes per sheet pan in a half-size oven).

3.1.9 *idle energy rate*—oven's rate of energy consumption (kBtu/h or kW), when empty, to maintain its cavity temperature at the thermostat set point.

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[2] *Annual Book of ASTM Standards*, Vol 05.06.

[3] Available from American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1791 Tullie Circle, NE, Atlanta, GA 30329. Phone (404) 636-8400.

3.1.10 *light load*—load (lb) during a cooking energy efficiency test consisting of approximately 14.5 lb (6.6 kg) of potatoes on a single pan placed on the center rack of the oven (7.25 lb (3.29 kg) of potatoes in a half-size oven).

3.1.11 *measured energy input rate*—peak rate (kBtu/h or kW) at which an oven will consume energy, measured during a period (typically, its preheat period) when it is known that the oven is operating at full input, including the fan at high speed.

3.1.12 *medium load*—load (lb) during a cooking energy efficiency test consisting of approximately 14.5 lb (6.6 kg) of potatoes on each of three sheet pans spaced evenly in a full-size oven (7.25 lb (3.29 kg) of potatoes per sheet pan in a half-size oven).

3.1.13 *pilot energy rate*—rate of energy consumption (kBtu/h) by a gas oven's standing pilot during non-cooking periods, if applicable.

3.1.14 *preheat energy*—amount of energy consumed (kBtu or kWh) by the oven while preheating its cavity from ambient temperature to the oven's thermostat set point.

3.1.15 *preheat time*—time (min) required for the oven cavity to preheat from ambient temperature to the thermostat set point.

3.1.16 *production capacity*—maximum rate of food cooked (lb/h) in an oven based on cooking potatoes during heavy-load cooking energy efficiency tests.

3.1.17 *production rate*—rate of food cooked (lb/h) in an oven based on cooking potatoes during cooking energy efficiency tests.

3.1.18 *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.

3.1.19 *uncertainty*—a measure of the combination of the bias and precision error in specified instrumentation or the measure of the repeatability of a reported test result.

4. Summary of Test Methods

4.1 *Thermostat Calibration*—The accuracy of the oven thermostat is checked at 350°F (177°C), the set point for all but the browning test, which is 300°F (149°C). This is accomplished by comparing the oven's temperature control setting with the temperature at the center of the oven's cavity. If necessary, the control is adjusted so that the maximum difference between its reading and the temperature at the center of the cavity is no more than ±5°F (±2.8°C).

4.2 *Preheat Energy Consumption and Time*—The time and energy required to preheat the oven from room temperature (75 ± 5°F) to 340°F is determined.

4.3 *Energy Input Rate*—The input rate of the oven is determined to check whether the oven is operating properly. If the measured input rate is not within 5 % of the rated input, all further testing ceases until the appliance can be made to operate within this specification. For gas ovens, the pilot energy rate and the fan and control energy rate are also determined.

4.4 *Idle Energy Rate*—The idle energy rate (kBtu/h or kW) is determined with the oven set to maintain 350 ± 5°F (177 ± 2.8°C).

4.5 *Cooking Energy Efficiency and Production Capacity*—The cooking energy efficiency and production rate are determined during light-, medium-, and heavy-load cooking tests.

4.6 *Cooking Uniformity*—The uniformity of heating within the oven's cavity is determined and reported based on the average temperature on each rack during cooking tests (pans of ice simulating pans of frozen food).

4.7 *White Sheet Cake Browning*—The uniformity of browning from rack to rack is documented using white sheet cakes.

5. Significance and Use

5.1 *Thermostat Calibration*—This test is conducted to ensure that all test results are determined at the same bulk oven cavity air temperature.

5.1.1 The results of the following tests can be used by an operator to select a convection oven based on its energy consumption performance or its cooking performance. Also, the results allow an operator to understand an oven's energy consumption.

5.2 *Energy Input Rate*—This test is used to confirm the test oven's rated input and to ensure its proper operation during all testing.

5.3 *Fan and Control Energy Rate*—Information from this test can be used to estimate the cost of electricity required to operate a gas oven. This cost can be added to the cost of gas consumed to estimate the total cost of energy necessary to operate the oven.

5.4 *Pilot Energy Rate*—This test provides a measure of a gas oven's energy consumption rate during periods when its burner is not on.

5.5 *Preheat Energy Consumption and Time*—This test provides a measure of time and energy required to preheat the oven cavity from ambient temperature to the thermostat set point temperature.

5.6 *Idle Energy Rate*—This test provides a measure of an empty oven's energy consumption at a typical cooking temperature setting. It also provides an indicator of the combined effectiveness of components of the oven's design (for example, insulation, door seals, and combustion efficiency) that influence its energy consumption.

5.7 *Cooking Energy Efficiency*—This test provides a measure of the oven's energy efficiency while light, medium, and heavy loads are being cooked.

5.8 *Production Capacity*—This test provides information that allows an operator to select an oven that matches food output requirements.

5.9 *Cooking Uniformity*—This test provides information regarding the oven's ability to cook food at the same rate throughout the oven's cavity.

5.10 *White Sheet Cake Browning*—This test provides information regarding the oven's ability to brown white sheet cakes uniformly through its cavity.

6. Apparatus

6.1 *Watt-Hour Meter*, for measuring the electrical energy consumption of an oven or oven fan motor/controls, having 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 equal to or less than 100

W, the meter shall have a resolution of at least 1 Wh and a maximum uncertainty no greater than 10 %.

6.2 *Gas Meter*, for measuring the gas consumption of an oven, which 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 light, it shall have a resolution of at least 0.01 ft^3 and a maximum uncertainty no greater than 2 % of the measured value.

6.3 *Temperature Readout Device*, connected to bare-junction, thermocouple probes, with a range from 0 to 450°F (−17.8 to 232°C), a resolution of 0.1°F (0.06°C), and an uncertainty of ±1.0°F (±0.6°C), used to measure the temperature of air (ambient and cavity), potatoes, and ice/water mixture. The device readout shall be capable of displaying required average temperature(s) during cooking energy efficiency and cooking uniformity tests (minimum of 20 thermocouples needed).

6.4 *Counter Scale*, with a capacity of 20.0 lb (9.1 kg), a resolution of 0.01 lb (0.005 kg), and an uncertainty of ±0.01 lb (0.005 kg) to measure the weight of potatoes for the cooking energy efficiency tests, water for the cooking uniformity tests, and cake batter for the browning test.

6.5 *Canopy Exhaust Hood*, 4 ft (1.2 m) in depth, wall mounted with the lower edge of the hood 6 ft, 6 in. (1.98 m) from the floor, 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. (152 mm) past both sides of the cooking appliance and shall not incorporate side curtains or partitions. Makeup air shall be delivered through face registers or from the space, or both.

6.6 *Stopwatch*, for measuring time to the nearest 1 s.

6.7 *Gas Temperature Probe*, for measuring the temperature of natural gas supplied to an oven with a range from 50 to 100°F (10 to 37.8°C), resolution of 1.0°F (0.6°C), and uncertainty of ±1.0°F (±0.6°C).

6.8 *Gas Pressure Gage*, for measuring the pressure of natural gas supplied to an oven, with a range from 0 to 15 in. H_2O, resolution of 0.1 in. H_2O, and uncertainty of ±0.1 in. H_2O.

6.9 *Barometer*, for measuring atmospheric pressure, with a range from 28 to 32 in. Hg, resolution of 0.2 in. Hg, and uncertainty of ±0.2 in. Hg.

7. Reagents and Materials

7.1 Potatoes shall be fresh, whole, prewashed, U.S. No. 1 Russets. Size shall be 100 count. A minimum of ten cases is needed for three test runs of light-, medium-, and heavy-load cooking energy efficiency tests.

7.2 *Macaroni and Cheese*, a sufficient quantity of frozen, commercial-grade, ready-to-cook macaroni and cheese entrees, with a nominal weight between 4.5 and 4.75 lb per unit, shall be obtained from a food distributor. The frozen macaroni and cheese shall have an initial moisture content of 68 ± 2 %, by weight. The moisture content shall be verified using the procedure in Annex A2.

NOTE 1—Stouffer's Traditional macaroni and cheese has been shown to be an acceptable product for testing by PG&E.

7.3 *Aluminum Sheet Pans*—A minimum of five of each size is needed for cooking energy efficiency and browning tests. Sizes required: 18 by 26 by 1 in. (457 by 660 by 25 mm) for full-size ovens and 18 by 13 by 1 in. (457 by 330 by 25 mm) for half-size ovens.

7.4 *Mixer*, commercial, for mixing cake batter (browning test).

7.5 *Cake Mix*, Pillsbury Deluxe White, 5 lb (2.3 kg) per box. A minimum of 20 lb (9.1 kg) is required for full-size oven browning tests and a minimum of 10 lb (4.5 kg) is required for half-size oven browning tests.

7.6 *Paper Baking Liners*, to line sheet pans for browning tests.

8. Sampling, Test Units

8.1 *Oven*—A representative production model shall be selected for performance testing.

9. Preparation of Apparatus

9.1 Install the appliance according to the manufacturer's instructions under a 4-ft (1.2-m) deep canopy exhaust hood mounted against the wall, with the lower edge of the hood 6 ft, 6 in. (1.98 m) from the floor. Position the oven with the front edge of the oven door inset 6 in. (152 mm) from the vertical plane of the front edge of the hood, at the manufacturer's recommended working height. The length of the exhaust hood and active filter area shall extend a minimum of 6 in. (152 mm) past both sides of the oven. In addition, both sides of the oven shall be a minimum of 3 ft (0.9 m) from any side wall, side partition, or other appliance. The exhaust ventilation rate shall be based on 300 cfm per linear ft of hood length. (For example, a 3-ft (0.9-m) wide oven shall be ventilated, at a minimum, by a hood 4 by 4 ft (1.2 by 1.2 m), with a nominal air flow rate of 1200 cfm. The application of a longer hood is acceptable, provided the ventilation rate is maintained at 300 cfm per linear foot over the entire length of the active hood.) The associated heating or cooling system shall be capable of maintaining an ambient temperature of 75 ± 5°F (21 ± 2.8°C) within the testing environment when the exhaust ventilation system is working. The ambient air temperature shall be measured during each test at a location that is approximately 2 ft (0.6 m) horizontally from either side of the oven at a vertical height equal to the distance from the floor to the center of the oven cooking cavity.

9.2 Connect the oven to a calibrated energy test meter. For gas oven installations, a pressure regulator shall be installed downstream from the meter to maintain a constant pressure of gas during all tests. Install instrumentation to record both the pressure and temperature of the gas supplied to an oven, as well as the barometric pressure, during each test so that the measured gas flow (ft^3) can be corrected to standard conditions. For electric oven installations, a voltage regulator may be required to maintain constant name plate voltage during tests if the voltage supply is not within 2.5 % of the manufacturer's nameplate voltage.

9.3 For a gas oven, adjust (while the oven is preheating) the gas supply pressure downstream from the oven's pressure regulator to within 2.5 % of the operating manifold pressure specified by the manufacturer. For gas ovens, make adjustments to the oven following the manufacturer's recommendations for optimizing combustion.

9.4 For an electric oven, adjust (while the oven is preheating) the supply voltage to within 2.5 % of the operating voltage specified by the manufacturer.

NOTE 2—If an electric oven is rated for dual voltage (for example, 208/240 V), the voltage selected by the manufacturer or tester, or both, shall be reported. If an oven is designed to operate at two voltages without a change in the resistance of the heating elements, the performance of the oven (for example, preheat time) may differ at the two voltages.

NOTE 3—It is the intent of the testing procedure herein to evaluate the performance of an oven at rated gas pressure or electrical voltage.

9.5 Make the oven ready for use in accordance with the manufacturer's instructions. For ovens with nine rack positions, place a rack at rack positions 1, 3, 5, 7, and 9. For ovens with other than nine rack positions, place the five racks at positions so that they divide the cavity into approximately equal cooking zones. This applies to all tests with the exceptions described in 10.6.5. In all cases, Position No. 1 is the top most rack position.

9.6 The average temperature must be monitored using thermocouples and a readout device in the cooking energy efficiency test (10.6) and the cooking uniformity tests (10.7). The average temperature can be measured using two basic approaches during these tests. In one, the thermocouples are wired in parallel, so that the voltage each generates is averaged with that of other thermocouples. The resistance of all thermocouple circuits connected in parallel must be equal to obtain a true average temperature. If one or more thermocouples circuits are open-circuited, the indicated read will no longer be the true average. The second method is to do the averaging of the appropriate thermocouples in a data logger and display it with the data readout. This is also susceptible to open-circuited thermocouples.

10. Procedure

NOTE 4—Prior to commencement of testing, the tester should read the operating manual to understand thoroughly the operation of the oven being tested.

NOTE 5—Control options may allow the oven to be operated at different input rates, fan modes, moisture injection options, and moisture vent settings. For all tests, the oven is to be operated at the control setting that corresponds to its rated input. The fan should be operated in the continuous mode at its highest speed setting. No moisture shall be injected into the oven, and the moisture vent shall be fully opened.

NOTE 6—During all testing, the ambient air temperature is to be maintained at 75 ± 5°F (21 ± 2.8°C). The oven cavity air temperature shall be at 75 ± 5°F (21 ± 2.8°C) at the beginning of each test unless otherwise specified. No tests are to be conducted without operating the exhaust ventilation system.

10.1 *General*:

10.1.1 For gas convection ovens, the following shall be recorded for each test run:

(1) Gas higher heating value;

(2) Gas temperature (measured at energy meter);

(3) Gas pressure (measured at energy meter);

(4) Barometric pressure;

(5) Gas volume consumed, where applicable; and

(6) Measured energy input rate during test run.

NOTE 7—The preferred method of determining the higher heating value of gas supplied to the oven under test is with a calorimeter or gas chromatograph used in accordance with accepted laboratory procedures. It is recommended that all testing be performed with gas having a higher heating value (HV) of between 1000 and 1075 Btu/SCF.

10.1.2 For a gas oven, calculate the corrected gas energy consumption using the recorded values for the temperature, pressure, and higher heating value (HV) of the gas supplied to the oven during the test (11.3.5).

10.1.3 For electric ovens, the following shall be recorded for each test run:

(1) Voltage while elements are energized;

(2) Electricity consumed, where applicable; and

(3) Measured energy input rate during test run.

10.1.4 For an electric oven, adjust the voltage (while heating elements are energized) to the rated voltage ±2.5 % at the beginning of each test run. Check its value regularly throughout the test, and maintain it within this range or discontinue the test.

10.1.5 For each test run, confirm that the measured energy input rate (kBtu/h for a gas oven and kW for an electric oven) is within 5 % of the rated name plate input. If the difference is greater than 5 %, testing shall be terminated and the manufacturer contacted. The manufacturer may make appropriate changes or adjustments to the oven or choose to supply an alternative oven for testing.

10.2 *Thermostat Calibration*:

10.2.1 Install a thermocouple at the geometric center of the oven cooking cavity to record the center of the oven temperature. The vertical location of the oven's geometric center is on a rack placed in the center rack position. If the test oven has an even number of rack positions, the vertical location is half the distance between the two middle rack positions. The horizontal location of the geometric center is half the distance between the rear wall of the cavity and the oven door and half the distance between the left and right cavity wall.

10.2.2 Set the temperature control to 350°F (177°C) and preheat the oven. Allow the oven to idle for 60 min after the burners or elements commence cycling at the thermostat set point.

NOTE 8—Cycling commences when the oven ready light or heat on light goes off.

10.2.3 After the 60-min idle period, record the center of oven temperature at 30-s intervals for 15 min. Calculate the average of the 30 temperatures recorded, and record the resulting average center of oven temperature as described in 11.2.1. If this recorded temperature is 350 ± 5°F (177 ± 2.8°C), the oven's thermostat is calibrated.

10.2.4 If the average center of oven temperature is not 350 ± 5°F (177 ± 2.8°C), repeat the step given in 10.2.3, and adjust the oven's temperature control following the manufacturer's instructions until it is within this range. Record the oven temperature control setting corresponding to 350 ± 5°F (177 ± 2.8°C) as described in 11.2.2. If calibration is not recommended or not easily accomplished, mark (on the dial) the exact position of the temperature control that corresponds to an average center of oven temperature of 350 ± 5°F (177 ± 2.8°C).

10.3 *Energy Input Rate and Preheat Energy Consumption and Time*:

10.3.1 For a gas oven, monitor and record the electricity consumed by the oven's fan and controls. Connect its electrical supply cord to an electrical meter capable of recording the electricity consumed to the nearest watt hour. Start recording this consumption when the burners actually ignite (not when the oven ready light comes on), and stop at the end of the preheat. Calculate and report the fan/control energy rate (11.3.3).

10.3.2 With the temperature controls set to maintain the average cavity air temperature at 350 ± 5°F (177 ± 2.8°C) (as determined in 10.2), turn the oven on.

10.3.3 Record the oven cavity temperature at a minimum of 5-s intervals during the course of preheat.

10.3.4 Record the time and energy consumption required to preheat the oven cavity air temperature from 75 ± 5°F to 340± 5°F (21 ± 2.8°C to 177 ± 2.8°C). Record these values for the time from when the unit was turned on (ready light comes on) until the burners or elements commence cycling (11.4).

10.3.5 Continue recording oven cavity temperature at a minimum of 5-s intervals until the temperature has exceeded, then returned to 350°F to characterize any possible temperature overshoot.

10.3.6 Calculate and record the oven's energy input rate (kBtu/h or kW) (11.3.2), and compare the result to the oven's nameplate-rated input in Btu/h or kW. For gas ovens, only the burner energy consumption (11.3.5) is to be used to compare the calculated energy input rate with the rated input.

10.4 *Pilot Energy Rate*:

10.4.1 For a gas oven with a standing pilot, set the gas valve controlling gas supply to the oven at the pilot position. Also set the oven's temperature control to the off position.

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

10.4.3 Monitor gas consumption for a minimum of 8 h of pilot operation. Calculate and report the pilot energy rate (11.3.7).

10.5 *Idle Energy Rate*:

10.5.1 With the temperature controls set to maintain the average cavity air temperature at 350 ± 5°F (177 ± 2.8°C) (10.2), turn the oven on. Allow it to idle at 350°F (177°C) for at least 60 min after the burners or elements have commenced cycling before beginning to monitor its energy consumption. For the gas oven, monitor only the gas consumed by the burner(s).

10.5.2 Record the oven's energy consumption while it is idling at 350°F (177°C) for a minimum of 3 h. Record the length of the idle period (11.6.1).

10.5.3 Calculate and record the oven's idle energy rate (kBtu/h or kW) for a cavity air temperature of 350°F (177°C) (11.6.1).

10.6 *Cooking Energy Efficiency and Production Capacity*:

NOTE 9—Cooking energy efficiency (CEE) tests are to be run using potatoes as the food product for three loading scenarios: light, medium, and heavy loads. Potatoes are used since their composition makes it relatively easy to calculate the amount of energy they absorb during cooking. The CEE test is to be run a minimum of three times for each loading scenario. Additional test runs may be necessary to obtain the required precision for the reported test results (see Annex A1). The minimum of three test runs for each loading scenario shall be run on the same day within as short a time period as possible. This can be accomplished by preparing a minimum of three loads prior to starting the cooking test (see 10.6.1-10.6.3).

10.6.1 For testing a full-size oven, obtain fifteen 18 by 26 by 1-in. (457 by 660 by 25-mm) sheet pans. For a half-size oven, use fifteen 18 by 13 by 1-in. (457 by 330 by 25-mm) sheet pans. Identify each sheet pan with a number from 1 to 15. For each test run, record the dry weight of each sheet pan to the nearest 0.01 lb (0.005 kg).

10.6.2 Prepare a minimum number of loads for three test runs using the number of pans required for the loading scenario (see Table 1). For testing a full-size oven, place 30 potatoes (three rows of ten potatoes per row) on each pan. The weight of the potatoes on each pan shall be 14.50 ± 0.30 lb (6.6 ± 0.14 kg). For a half-size oven, place 15 potatoes (three rows of five potatoes per row) on each pan. The weight of the potatoes on these pans shall be 7.25 ± 0.30 lb (3.3 ± 0.14 kg). Record the weight of the potatoes on each pan. For each test run, record the total weight of all of the potatoes as the initial potato weight. Record all weights to the nearest 0.01 lb (0.005 kg).

NOTE 10—If the weight of the potatoes on a pan is outside the 14.50 ± 0.30-lb (6.6 ± 0.14-kg) or 7.25 ± 0.30-lb (3.3 ± 0.14-kg) weight range specified above, substitute smaller or larger potatoes, as necessary, until the weight of the potatoes on each pan is within one of the appropriate required weight ranges.

10.6.3 Once the pans of potatoes have been prepared, mark selected potatoes to be monitored for temperature. For a light-load test run, mark every other potato on the pan. For medium- and heavy-load test runs, mark randomly selected potatoes on each pan (three for heavy-load runs and five for medium-load runs). For each test run, record the position of the marked potatoes on each pan according to the positions shown in Fig. 1.

NOTE 11—For a given pan, monitor potatoes at different combinations of locations for each test run. For example, if for Run No. 1, potatoes on Pan No. 5 are monitored at Location Nos. 5, 17, and 29, potatoes on this pan are not to be monitored at this same combination of locations during subsequent test runs.

10.6.4 Shortly before each test run, place the bead of a bare junction thermocouple into the center of the marked potatoes being cooked. Secure each thermocouple lead wire in such a manner that its junction will remain at the center of the potato throughout the cooking period. Ensure that the temperature readout device displays the average temperature of all of the monitored potatoes (see 9.6). The temperature of the potatoes at the start of each test shall be 75 ± 5°F (21 ± 2.8°C).

TABLE 1 Pan Placement for Cooking Energy Efficiency Tests

Loading Scenario	Number of Pans Required	Rack Positions[A]
Light	1	5
Medium	3	2, 5, 8
Full	5	1, 3, 5, 7, 9

[A] For ovens with nine rack positions. See 9.5 for ovens with other than nine rack positions. Rack Position No. 1 is the top-most position.

3	6	9	12	15	18	21	24	27	30
2	5	8	11	14	17	20	23	26	29
1	4	7	10	13	16	19	22	25	28

FIG. 1 Position of Potatoes on Sheet Pans

10.6.5 Place oven racks in the positions as shown in Table 1. Preheat the oven to 350°F (177°C), and allow it to idle for 1 h prior to the start of the first test run. Once this time period has elapsed, wait for the oven elements or burners to cycle one additional time before starting the test run to ensure that the oven cavity air temperature is at 350°F (177°C).

10.6.6 When the oven ready light or heat on light goes off, begin recording the oven energy consumption. Open the oven door immediately, and allow it to remain open for the entire loading period, as indicated in Table 2. Do not close the door, even if the pan loading is completed in less than the allotted time. Load the pans of potatoes by centering them on the oven racks during this period. At the end of the load period, close the oven door and record the initial average potato temperature to the nearest 0.1°F (0.06°C). Record the time as the beginning of the cooking period.

10.6.7 Monitor the average potato temperature during cooking. When it reaches 205°F (99°C), shut the oven off immediately, and record the amount of energy consumed and elapsed cook time to the nearest 0.1 min. (Cook time is the time from when the oven door is closed until the oven is shut off.) Remove the thermocouples from the potatoes, and quickly remove all of the pans from the oven prior to weighing them. Record the final weight of each pan of potatoes within the maximum allowed time (see weighing period in Table 2) as measured from the time at which the oven was shut off. Calculate and record the final weight of the potatoes in each pan. Record the sum of these five weights as the final potato weight. Record all weights to the nearest 0.01 lb (0.005 kg). Calculate the oven's cooking energy efficiency, production rate, and cooking energy rate (see 11.7). Once the pans have been removed from the oven, close the door and restart the oven. Idling the oven for 1 h between test runs is not necessary.

10.6.8 Perform Run Nos. 2 and 3 by repeating the steps given in 10.6.4-10.6.7. Follow the procedure in Annex A1 to determine whether more than three test runs are required. Report the results for the cooking energy efficiency, production rate, cooking energy rate, and cook time as described in Annex A1.

10.7 *Cooking Uniformity Test*:

TABLE 2 Elapse Times for Loading and Weighing During Cooking Energy Efficiency Tests

Loading Scenario	Loading Period (min)	Weighing Period, max (min)
Light	1	1
Medium	2	3
Full	3	5

NOTE 12—The objective of this test is to evaluate the cooking uniformity of the oven under heavy food loading conditions such as heating pans of frozen food. The results of this test describe the oven's cooking uniformity by a comparison of the average temperature of food on each rack. Each rack's reported average temperature is obtained by averaging the results of three test runs. This test is to be performed so that the variation in the average temperature among the racks is minimized.

10.7.1 Obtain the required number of pans of frozen macaroni and cheese entrees. Use 20 pans for a full-size oven test or 10 pans for a half-size oven test. Install one thermocouple in the center of each pan by drilling a small hole in the frozen mass and running the thermocouple underneath the foil cover (see Fig. 2). Secure the thermocouple to the pan with a small binder clip to prevent it from coming loose during the test.

10.7.2 The racks shall be placed in the oven as described in 9.5. Install stops on oven racks to ensure that pan placement on each rack is the same from test run to test run. This is accomplished by positioning the pans on the racks so that the four- or two-pan group is as close to the center of the rack as possible, with 0.5 in. (12.7 mm) of space left between pans, left to right and back to front (see Fig. 3).

10.7.3 Perform three test runs as indicated in 10.7.4-10.7.8, using the correct loading sequence as determined in 10.7.7 or 10.7.11. Average the temperatures obtained from the three test runs for each rack. Report the average temperature for each rack as indicated in 11.5.

10.7.4 Weigh and record the initial weight of each macaroni and cheese pan. Stabilize the instrumented pans of macaroni and cheese in a freezer at –5 ± 5°F.

10.7.5 Preheat the oven to 350°F (177°C), and allow its cavity to stabilize for 1 h.

10.7.6 Allow the oven to cycle one additional time, and then open the oven door when the oven ready or heat on light shuts off. Leave the oven door open for the entire allowable loading period: 2.50 min for a full-size oven test or 1.25 min for a half-size oven test. Do not close the door, even if the pan loading is completed in less than the allotted time.

10.7.7 Load the pans of macaroni and cheese into the oven from back to front. Place each pan into the oven with its

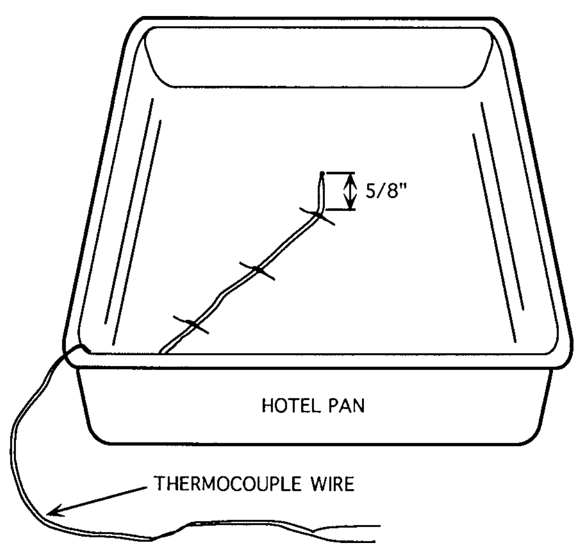

FIG. 2 Thermocouple Probe Placement in Hotel Pan

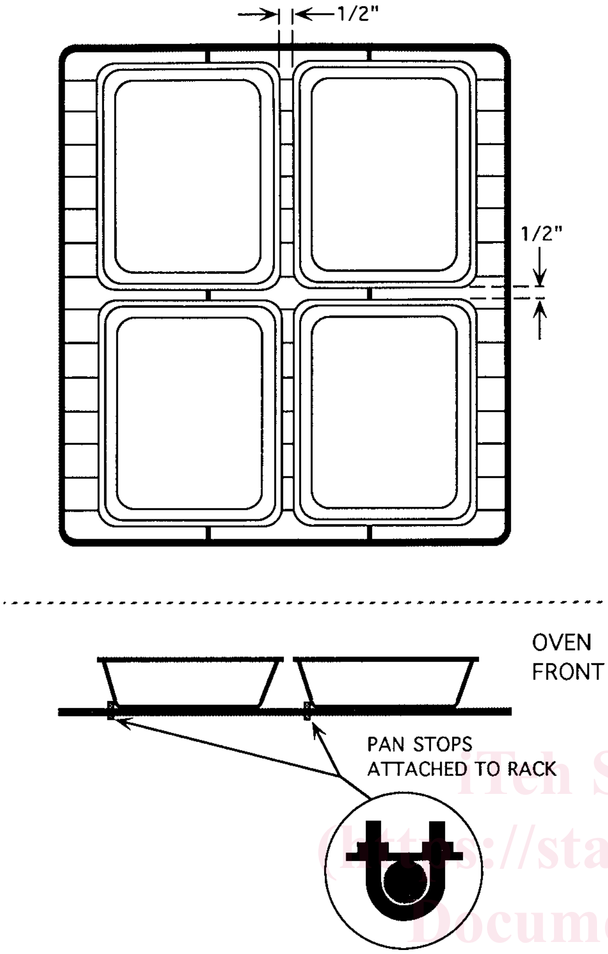

FIG. 3 Hotel Pan Placement on Oven Racks

longest side parallel to the back of the oven. Place four pans on each rack when testing a full-size oven and two pans on each rack when testing a half-size oven. Follow the manufacturer's recommendation for loading the pans from the top to bottom rack or vice versa. If a recommended loading sequence is not provided, follow the steps given in 10.7.11. Otherwise, perform each test run as described in 10.7.8-10.7.10.

NOTE 13—The intent of this test procedure is to load the oven (that is, top down or bottom up) so that the variation in average temperature among the racks is minimized.

10.7.8 Close the oven door at the end of the loading period, and begin to monitor the elapsed time, oven energy consumption, and the average temperature of the macaroni and cheese. Terminate the test run when the average macaroni and cheese temperature reaches 170°F (71°C). Record the elapsed time from when the oven door was closed as the cook time.

10.7.9 Weigh and record the weight of the cooked pans of macaroni and cheese.

10.7.10 Identify which rack had the highest average macaroni and cheese temperature. Record this rack as the fastest cooking rack. Record the average temperature on each of the other racks. Identify the slowest cooking rack.

10.7.11 Perform two test runs as described in 10.7.8-10.7.10 to determine the proper loading sequence. Perform the first run by loading the pans starting with the top rack and working down. For the second run, start loading from the bottom rack and work up. Compare the results of the two runs to determine the correct loading sequence for the oven (Run No. 1, top-down, or Run No. 2, bottom-up). The correct sequence is the one that results in the smallest difference between the hottest and coldest rack temperature. Having determined the correct loading sequence, perform two additional runs (Run Nos. 3 and 4) as described in 10.7.8-10.7.10. Combine the results from the run with the correct loading sequence (Run No. 1 or 2) with these results.

10.7.12 Determine the frozen-load cooking energy efficiency and frozen-load production capacity in accordance with 11.8.3 and 11.8.4.

10.8 *Browning Test (White Sheet Cakes)*:

NOTE 14—The objective of this test is to evaluate the browning uniformity of the oven using white sheet cakes. The oven's browning uniformity is reported by describing the browning pattern of the sheet cake baked on each rack. As with the cooking uniformity test, this test is to be performed so that the variation in browning from rack to rack is minimized.

10.8.1 Place racks in the oven as described in 9.5.

10.8.2 Preheat the oven to 300°F (149°C), and allow its cavity temperature to stabilize for 1 h.

10.8.3 Obtain five 18 by 26 by 1-in. (457 by 660 by 25-mm) sheet pans for testing a full-size oven or five 18 by 13 by 1-in. (457 by 330 by 25-mm) sheet pans for testing a half-size oven. Line each sheet pan with a paper liner.

10.8.4 Scale 6.0 ± 0.1 lb (2.7 ± 0.05 kg) of cake batter into each 18 by 26 by 1-in. (457 by 660 by 25-mm) sheet pan or 3.0 ± 0.1 lb (1.4 ± 0.05 kg) of batter into each 18 by 13 by 1-in. (457 by 330 by 25-mm) sheet pan. Level the batter in each pan with a spatula. Lightly drop each pan several times to reduce the number of air bubbles in the batter.

10.8.5 If more than one pan orientation on the racks is possible, obtain and follow the manufacturer's recommendations for orienting the pans. If a recommendation is not provided, load each pan with the longest side of the pan parallel to the back of the oven and centered on the rack. Record by rack which pan orientation is used for the test.

10.8.6 In performing the test, obtain and follow the manufacturer's recommendations for the pan loading sequence (that is, from top rack down or from bottom rack up). If this loading sequence is not provided, follow the steps given in 10.8.7 to determine the correct loading sequence. Otherwise, proceed to 10.8.8.

10.8.7 To determine the correct pan loading sequence, perform at least two test runs following the procedure given in 10.8.8 and 10.8.9. The objective of these runs is to determine which loading sequence (top-down or bottom-up) has the least effect on the browning uniformity from rack to rack. This occurs when the first cake loaded is no darker than another cake at the end of the test. For the first run(s), load the first pan onto the top rack and work down. If the cakes are found to be overdone or underdone, run additional tests using this loading sequence until the cake doneness criteria given in 10.8.9 are satisfied. Once these criteria have been satisfied, record whether the cake on the top or on the bottom rack is darker. Next, reverse the loading sequence by loading the first pan onto the bottom rack and working up. Again, if the cake doneness criteria are not satisfied, repeat the test with this loading sequence until they are satisfied. Then report which cake is darker, the one on the top rack or the one on the bottom rack. Finally, determine which type of run, top-down or bottom-up, resulted in the minimum variation in browning uniformity. Use the results of that test run in reporting the test results as described in 11.9.

10.8.8 When the oven ready or heat on light shuts off, open the oven door and load the five sheet pans into the oven following the loading sequence and orientation, if applicable, as determined in 10.8.5 and 10.8.6. Allow 30 s to load the oven, and then close the door. Bake the cakes according to the instructions on the cake mix box.

NOTE 15—For example, research at PG&E's Food Service Technology Center has found that with the oven thermostat set at 300°F (149°C), the cook time for the cakes in a tested full-size oven is 18.5 min, while the cook time in a tested half-size oven is 16.0 min.

10.8.9 Determine whether the sheet cakes are done by first inserting a skewer into the center of each cake. The individual cake is considered done if no moist particles cling to it when it is withdrawn. Whether the cake load is done properly, overdone, or underdone is determined by the color of the cakes. If less than three of the cakes are golden or darker in color (Fig. 3), the cakes are considered underdone, and the cook time should be lengthened. If three or more cakes are dark brown, the cakes are overdone, and the cook time should be shortened. If underdone or overdone, browning uniformity cannot be determined. When cakes are cooked too long, browning will tend to become uniformly dark. If a cook time adjustment is required, repeat the steps given in 10.8.2-10.8.7 until an acceptable level of doneness is attained. Record the cook time required to achieve proper doneness.

10.8.10 Report the results of the test run as described in 11.9.

11. Calculation and Report

NOTE 16—The results of each test are calculated, recorded, and reported as described in this section. A summary of the reported results is given in Annex A2.

11.1 *Test Oven*—Summarize the physical and operating characteristics of the oven, reporting all manufacturer's specifications and deviations therefrom.

11.2 *Thermostat Accuracy*:

11.2.1 For the as-received condition, report the center of oven temperatures that correspond to the 350°F (177°C) settings on the oven's temperature control (10.2.3).

11.2.2 If the oven's temperature control is adjusted to bring it within 5°F (2.8°C) of the center of the oven temperature, for the as-adjusted condition, report the oven temperature control setting that corresponds to 350 ± 5°F (177 ± 2.8°C) at the center of the oven as determined in 10.2.4.

11.3 *Energy Input Rate*:

11.3.1 Report the manufacturer's rated energy input (nameplate) in kBtu/h for a gas oven and kW for an electric oven.

11.3.2 Calculate and report the maximum energy input rate (Btu/h or kW) based on the energy consumed by the oven during the preheat period using the following:

$$q_{input} = \frac{E \times 60}{t} \quad (1)$$

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.

The conversion factor is 60 min/h.

11.3.3 For a gas oven, calculate and report the oven's fan/control energy rate (kW) using the following:

$$q_{fan} = \frac{E_{fan} \times 60}{t_{preheat}} \quad (2)$$

where:

q_{fan} = measured peak energy input rate, Btu/h or kW,
E_{fan} = fan energy consumed during the preheat period, Wh, and
$t_{preheat}$ = measured preheat time, min.

The conversion factors are 60 min/h and 1000 Wh/kWh.

11.3.4 Calculate and report the percent difference between the manufacturer's nameplate energy input rate and the measured energy input rate.

11.4 *Preheat Energy and Time*:

11.4.1 Report the preheat energy consumption (kBtu or kWh, or both), and the preheat time (min), as determined in 10.3.

11.4.2 For a gas oven, report the preheat energy due to fan and control energy consumption (kWh) separately from the burner energy consumption (kBtu).

11.4.3 Calculate and report the average preheat rate (°F/min) based on the preheat period.

11.4.4 Generate a graph showing oven cavity temperature versus time for the preheat period including temperature overshoot, if any.

11.5 *Pilot Energy Rate*:

11.5.1 Calculate and report the pilot energy rate (Btu/h (kJ/h)) based on the following:

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

where:

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

11.6 *Idle Energy Rate*:

11.6.1 Calculate and report the oven's idle energy rate (kBtu/h or kW) based on the idle energy consumption determined in 10.5 using the following:

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

where:

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

11.7 *Cooking Energy Efficiency and Production Capacity*:

NOTE 17—The following paragraphs describe how the cooking energy rate, cooking energy efficiency, and production capacity are calculated. The average values of these parameters, along with the average cook times, are to be calculated based on a minimum of three test runs and then reported as described in A1.1 of Annex A1.

11.7.1 Calculate and report the cooking energy rate for heavy-, medium-, and light-load cooking tests based on the following:

$$q_{potato} = \frac{E \times 60}{t} \quad (5)$$

where:

q_{potato} = cooking energy rate, Btu/h (kJ/h) or kW,
E = energy consumed during cooking test, Btu (kJ) or kWh, and
t = cooking test period, min.

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

11.7.2 Calculate and report the energy consumption per pound of food cooked for heavy-, medium-, and light-load cooking tests based on the following:

$$q_{per\ pound} = \frac{E}{W} \quad (6)$$

where:

$q_{per\ pound}$ = energy per pound, Btu/lb (kJ/kg) or kWh/lb (kWh/kg),
E = energy consumed during cooking test, Btu (kJ) or kWh, and
W = total initial weight of the potatoes, lb (kg).

11.7.3 Calculate and report the cooking energy efficiency for heavy-, medium- and light-load cooking tests based on the following:

$$\eta_{potato} = \frac{E_{potato}}{E_{oven}} \times 100 \quad (7)$$

where:

η_{potato} = cooking energy efficiency, %,
E_{potato} = energy into the potatoes, Btu (kJ), and
E_{oven} = $E_{sens,potato} + E_{evap,potato}$.

where:

$E_{sens,potato}$ = quantity of heat added to the potatoes, which causes their temperature to increase from the starting temperature to the final temperature (205°F), Btu (kJ)
= $(W_{i,potato})\ (C_{p,potato})\ (T_{f,potato} - T_{i,potato})$

where:

$W_{i,potato}$ = initial weight of potatoes, lb (kg),
$C_{p,potato}$ = specific heat of potatoes, Btu/lb, °F (kJ/kg, °C),
= 0.84.

NOTE 18—For this analysis, the specific heat (C_p) of a load of potatoes is considered to be the weighted average of the specific heat of its components (for example, water and nonfat protein). Research conducted by PG&E determined that the weighted average of the specific heat for potatoes cooked in accordance with this test method was approximately 0.84 Btu/lb* °F.

$T_{f,potato}$ = average temperature of all of the potatoes at the end of the cooking test, °F,
$T_{i,potato}$ = average temperature of all of the potatoes at the beginning of the cooking test, °F,
$E_{evap,potato}$ = latent heat (of vaporization) added to the potatoes, which causes some of the moisture contained in the potatoes to evaporate. The heat of vaporization cannot be perceived by a change in temperature and must be calculated after determining how much moisture was lost during baking.
= $(W_{f,potato} - W_{i,potato}) \times H_v$

where:

$W_{f,potato}$ = final weight of the baked potatoes, lb (kg),
$W_{i,potato}$ = initial weight of the raw potatoes, lb (kg),
H_v = heat of vaporization, Btu/lb (kJ/kg),
= 970 Btu/lb (2256 kJ/kg), and
E_{oven} = energy into the oven, Btu (kJ).

11.7.4 Calculate and report the production rate (PR) (lb/h) for the oven as follows:

$$\mathrm{PR}_{potato} = \frac{W_{\mathrm{i},potato} \times 60}{t_{\mathrm{cook},potato}} \quad (8)$$

where:

$W_{\mathrm{i},potato}$ = initial weight of the potatoes on all pans (lb) during the light-, medium-, or heavy-load cooking-energy efficiency test, and
$t_{\mathrm{cook},potato}$ = cook time for the light-, medium-, or heavy-load cooking test (min).

11.7.5 Report the cook time for the heavy-, medium-, and light-load tests.

11.8 *Cooking Uniformity Test*:

11.8.1 For each rack, calculate the average temperature of the macaroni and cheese in the pans at the end of the test using the corresponding average temperatures for the three test runs. Report these average temperatures for each of the five racks.

11.8.2 Calculate and report the frozen-load cooking energy rate based on the following:

$$q_{frozen-load} = \frac{E \times 60}{t} \quad (9)$$

where:

$q_{frozen-load}$ = frozen-load cooking energy rate, Btu/h (kJ/h) or kW,
E = energy consumed during the cooking uniformity test, Btu (kJ) or kWh, and
t = cooking uniformity test period, min.

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

11.8.3 Calculate and report the frozen-load cooking energy efficiency based on the following:

$$\eta_{\mathrm{frozen-load}} = \frac{E_{food}}{E_{oven}} \times 100 \quad (10)$$

where:

$\eta_{\mathrm{frozen\text{-}load}}$ = frozen-load cooking energy efficiency, %,
E_{food} = energy into the frozen macaroni and cheese, Btu (kJ), and

$E_{oven} = E_{sens,frozen\text{-}load} + E_{thaw,frozen\text{-}load} + E_{evap,frozen\text{-}load}$.

where:

$E_{sens,frozen\text{-}load}$ = quantity of heat added to the frozen macaroni and cheese, which causes its temperature to increase from the starting temperature to the final temperature, (170°F), Btu (kJ)
= $(W_{i,frozen\text{-}load})(C_{p,frozen\text{-}load})(T_{f,frozen\text{-}load} - T_{i,frozen\text{-}load})$

where:

$W_{i,frozen\text{-}load}$ = initial weight of the frozen macaroni and cheese load, lb (kg),
$C_{p,frozen\text{-}load}$ = average specific heat of the frozen macaroni and cheese load, Btu/lb, °F (kJ/kg, °C),
= 0.695 (0.898).

NOTE 19—For this analysis, the specific heat ($C_{p,frozen\text{-}load}$), of frozen macaroni and cheese is considered to be the weighted average of the specific heat of its components (for example, water, fat, and nonfat protein). Research conducted by PG&E determined that the weighted average of the specific heat for frozen macaroni and cheese cooked in accordance with this test method was approximately 0.695 Btu/lb, °F (0.898 kJ/kg,° C).

$T_{f,frozen\text{-}load}$ = final average temperature of the cooked macaroni and cheese, °F (°C),
$T_{i,frozen\text{-}load}$ = initial temperature of the frozen macaroni and cheese load, °F (°C),
$E_{thaw,frozen\text{-}load}$ = latent heat (of fusion) added to the macaroni and cheese, which causes the moisture (in the form of ice) contained in the product to melt when the temperature of reaches 32°F (0°C) (the additional heat required to melt the ice is not reflected by a change in the temperature of the product), Btu (kJ)
= $W_{iw} \times H_f$

where:

W_{iw} = initial weight of water in frozen macaroni and cheese, lb (kg),
H_f = heat of fusion, Btu/lb (kJ/kg), and
= 144 Btu/lb (336 kJ/kg) at 32°F (0°C).
E_{evap} = latent heat (of vaporization) added to the macaroni and cheese, which causes some of the moisture contained in the product to evaporate. Similar to the heat of fusion, the heat of vaporization cannot be perceived by a change in temperature and must be calculated after determining how much moisture was lost during cooking.
= $(W_{f,frozen\text{-}load} - W_{i,frozen\text{-}load}) \times H_v$

where:

$W_{f,frozen\text{-}load}$ = final weight of the cooked macaroni and cheese, lb (kg),
$W_{i,frozen\text{-}load}$ = initial weight of the frozen macaroni and cheese, lb (kg),
H_v = heat of vaporization, Btu/lb (kJ/kg),
= 970 Btu/lb 2256 kJ/kg) at 212°F (100°C), and
E_{oven} = energy into the oven, Btu (kJ).

11.8.4 Calculate frozen-load production capacity (lb/h (kg/h)) based on:

$$PC_{frozen-load} = \frac{W_{i,frozen-load} \times 60}{t_{frozen-load}} \quad (11)$$

where:

$PC_{frozen\text{-}load}$ = frozen-load production capacity of the oven, lb/h (kg/h),
$W_{i,frozen\text{-}load}$ = total initial weight of the frozen macaroni and cheese load, lb (kg), and
$t_{frozen\text{-}load}$ = total time required to cook the frozen macaroni and cheese load, min.

11.9 *Browning Test (White Sheet Cakes)*:

11.9.1 Note and record the color at the center and 1 in. from each corner of each cake according the color chart (Fig. 3).

11.10 Provide a written description of the browning pattern and any irregularities for each sheet cake. Also, note any differences in browning patterns and irregularities from cake to cake. A sketch or photograph of each cake showing its browning pattern and any irregularities may accompany the description.

11.11 If the orientation of the sheet pan on each rack was an option, report the orientation of the pan on each rack used during the test. Report the cake load cook time.

12. Precision and Bias

12.1 *Precision*:

12.1.1 *Repeatability (Within Laboratory, Same Operator and Equipment)*:

12.1.1.1 For each cooking energy efficiency result and for the heavy-load production rate (production capacity) result, the percent uncertainty in each result, based on at least three test runs, has been specified to be no greater than ±10 %.

12.1.1.2 The repeatability of each remaining reported parameter, with the exception of the browning uniformity, is being determined. The repeatability of the browning uniformity cannot be determined because of the descriptive nature of the test result.

12.1.2 *Reproducibility (Multiple Laboratories)*—The interlaboratory precision of the procedure in this test method for measuring each reported parameter, with the exception of the browning uniformity, is being determined. The reproducibility of the browning uniformity cannot be determined because of the descriptive nature of the test result.

12.2 *Bias*—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 browning; convection oven; cooking energy efficiency; cooking uniformity; energy efficiency; energy input; energy