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An American National Standard

Standard Test Method for Commercial Coffee Brewers[1]

This standard is issued under the fixed designation F2990; 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 covers the evaluation of the energy consumption, brewing, and holding performance of commercial coffee brewing machines (here after referred to as coffee brewers) used in commercial and institutional facilities. The operator can use this evaluation to select a coffee brewer and characterize its energy use and performance. This test method does not cover residential coffee brewers, "urn" coffee brewers (***Type III***), or espresso machines.

1.2 This test method applies to single cup (***Type I***) and batch (***Type II***) coffee brewers. The coffee brewer will be tested for the following (where applicable):

1.2.1 Maximum energy input rate,

1.2.2 Heavy use brewing energy consumption,

1.2.3 Production capacity,

1.2.4 "Ready-to-Brew" (Standby/Idle) energy rate, and

1.2.5 "Energy Save Mode" (Low power) energy rate.

1.3 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.

1.4 *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]

F2988 Specification for Commercial Coffee Brewers

2.2 *ASHRAE Standard:*

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

3. Terminology

3.1 *Definitions:*

3.1.1 *coffee brewer, n*—commercial appliances designed to heat water and brew coffee.

NOTE 1—Cold water is poured into a separate chamber (manually or automatically), which is then heated up to just below the boiling point, and directed through the filter. This process is also called *automatic drip-brew*.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *brew cycle, n*—the total time required to dispense a single cup (***Type I***) or batch (***Type II***) of coffee, starting with the initiation of a brew event by the user, and including the time needed for the machine to recover to a "ready to brew" state.

3.2.2 *brew event, n*—the sequence of brewing a single cup (***Type I***) or batch (***Type II***) of coffee, starting with initiation by the user, and including the time for the remaining water to drip through the filter.

3.2.3 *brew energy, n*—energy consumed by coffee brewer during a brew cycle.

3.2.4 *warmer energy, n*—the energy consumed by the plate warmer while maintaining the delivered brew volume at serving temperature.

NOTE 2—Warmers may not be an applicable feature of single serving Type I machines.

3.2.5 *ready-to-brew (standby/idle) energy, n*—energy required by the coffee brewer to maintain "ready to brew" conditions including energy required to keep the reservoir tank at the brew set temperature.

3.2.6 *energy save mode, n*—an optional low power mode (different from the ready-to-brew state) that is designed by the manufacturer to use less energy while the coffee brewer still remains "on."

NOTE 3—Energy Save Modes are typically specified by the manufacturer and outlined in the user manual. Some examples may include an automatic reduction of tank holding temperature (for example, 140°) or burner temperature after a certain period of machine un-use. The manual turning off of accessories is not considered to be an Energy Save Mode unless specified by the manufacturer.

3.2.7 *production capacity, n*—calculated maximum volume of coffee that can potentially be brewed in one full hour and expressed in gal/h (L/h).

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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.

3.2.8 *brew volume, n*—the substantive beverage portion delivered during a single brew event, and specified in fluid ounces or gallons (millilitres or litres).

3.2.9 *serving temperature, n*—the temperature of the beverage delivered from a brewing machine, measured at the dispensing outlet, and expressed in degrees Farenheit (degrees Celsius).

3.2.10 *holding temperature, n*—the measured average internal temperature of a volume of dispensed beverage as maintained by the plate warmers and expressed in degrees Farenheit (degrees Celsius).

3.2.11 *recovery time, n*—the time required for the machine to return to brew set temperature ("ready to brew state") after a completed brew event.

4. Summary of Test Method

4.1 All testing is conducted using default factory settings for brewers that feature programmable settings. If not specified by the manufacturer, all plate warmers and accessories featuring adjustable input rates shall be conducted with all accessories and brewers at 100 % input ratings.

4.2 The coffee brewer is connected to the appropriate electrical and water metering devices. If applicable, the internal water tank is evacuated prior to testing. The measured maximum energy input is determined and checked against the rated input before continuing with testing. Total volume of water used to fill the tank will also be recorded.

4.3 The internal water tank temperature and energy consumption is monitored in the, preheating mode, ready-to-brew (idle) mode, energy save mode, and accessories (plate warmers) on and off.

4.4 Energy consumption and time are monitored while the coffee brewer is used to brew coffee sequentially to replicate a heavy use period.

5. Significance and Use

5.1 The measured maximum energy input rate is used to confirm that the coffee brewer is operating in accordance with its nameplate rating.

5.2 If applicable and accessible, the boiler or internal tank temperature is measured to ensure that the water is maintained at a ready-to-brew temperature. This can also be used later to normalize coffee brewer energy consumption to a standard temperature.

5.3 The Preheat Test can be used to gauge the amount of time and energy required for the coffee brewer to reach a ready-to-brew state from the ambient room and incoming water temperatures.

5.4 Ready-to-Brew and Energy Save Mode energy can be used by end users to estimate the amount of energy consumed while coffee is not being brewed.

5.5 Heavy-use energy consumption can be used to estimate how much energy is consumed by the coffee brewer when brewing coffee. Along with preheat and ready-to-brew (standby) energy, this value can be used by end users to model their machine energy use.

5.6 Production capacity is a calculated measure, determined through testing, to define the performance of the coffee brewer. End users can use this value to specify a brewer that matches their production needs.

6. Apparatus

6.1 *Watt-Hour Meter,* for measuring the electrical energy consumption coffee brewer, shall have a resolution of at least 0.1 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 0.1 Wh and a maximum uncertainty no greater than 1.5 %.

6.2 *Analytical Balance Scale,* for measuring weights up to 15 lb (6.8 kg), with a resolution of 0.001 lb (0.5 g) and an uncertainty of 0.001 lb (0.5 g).

6.3 *Data Acquisition System,* for receiving and saving data for energy and temperatures with an additional capability of displaying multiple temperature updating at least every two seconds.

6.4 *Stop Watch,* with a 1-second resolution.

6.5 *Flow Meter,* for measuring total water consumption of the appliance. Shall have a resolution of 0.01 gal (0.04 L) and an uncertainty of 0.01 gal (0.04 L) at a flow rate as low as 0.2 gpm (0.8 Lpm).

6.6 *Thermocouple Probe(s),* industry standard type T or type K thermocouples capable of immersion, with a range of from 50 to 400°F (10 to 204°C) and an uncertainty of ±1°F (±0.5°C).

6.7 *Carafe/Decanter(s),* a suitable container/receptacle shall be used to hold the brewed coffee volume for batch brewers (***Type II***). The volume of the container shall be rated in fluid ounces (mL) or gallons (L) depending on volumetric capacity.

6.8 *Cup(s),* appropriate size to accommodate the standard brew volume of the single cup (***Type I***) coffee brewer being tested. The volume of the container shall be rated in fluid ounces (mL).

6.9 When specified by manufacturer, installation of a water treatment device is required in hard-water areas for the incoming water supply. A tempering or pressure regulating device may also be needed to supply the manufacturer-specified incoming water temperature and pressure to the coffee brewer.

7. Reagents and Materials

7.1 *Water Specs*—Incoming water to the coffee brewer shall have a maximum hardness of three grains per gallon and shall be within 70 ± 5°F (21 ± 3°C). If the tester's water supply does not meet the specification, a water softener and/or tempering kit may be required.

7.2 *Coffee Grounds*—Generic coffee ground with a specified serving size of 0.125 lb ± 0.005 lb for every 64 oz (0.057 ± 0.002 kg for every 1.89 L) of hot water shall be used for batch

(***Type II***) brewers. If the coffee brewer dispenses single serving portions (***Type I***) using prefabricated modules, the weight of the spent coffee module will be recorded and used for analysis.

7.3 *Portafilter Basket*—For single cup (***Type I***) coffee brewers, a 58-mm "Double" espresso portafilter basket is used to record the temperature of the beverage as it exits the dispensing head of the machine.

7.4 *Coffee Filter(s)*—For batch (***Type II***) coffee brewers, use white paper coffee filters with a flat bottom and fit into the manufacturer's removable brew basket. The height of the filter paper is dependent on the amount of coffee ground or the brew basket dimensions so that coffee ground does not spill over the coffee filter during the brew process.

7.5 *High Temperature Fiberglass/Silicone Tape (500°F/ 260°C)*—Used to secure thermocouples, and other testing apparatus to regions of extremely high heat, up to 500°F (260°C), on the coffee brewing equipment to be tested. This tape should always be used on warming plates.

7.6 *Aluminum Foil Tape (325°F /163°C)*—High performance aluminum foil tape with a service operating temperature of -20°F to 325°F (-29°C to 163°C) used to secure thermocouples, portafilters and other testing apparatus to regions of high heat, up to 325°F (163°C), on the coffee brewing equipment to be tested.

8. Sampling, Test Specimens, and Test Units

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

9. Preparation of Apparatus

9.1 Install the coffee brewer according to the manufacturer's instructions in a controlled testing environment. All sides of the appliance shall be a minimum of 12-in. from any side wall, side partition, and at least 36 in. from any other operating commercial kitchen appliance. The associated heating or cooling system for the space shall be capable of maintaining an average ambient temperature of 75 ± 5°F (24 ± 3°C) within the testing environment.

9.2 Connect the coffee brewer to a calibrated test energy meter. A voltage regulator may be required during tests to ensure that the voltage supply is within ±1.0 % of the manufacturer's nameplate voltage. Confirm that the supply voltage is within ±1.0 % of the operating voltage specified by the manufacturer while the elements are energized. Record the test voltage for each test.

NOTE 4—It is the intent of the testing procedure herein to evaluate the performance of a coffee brewer at its rated 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 and/or tester shall be reported. If a coffee brewer is designed to operate at two voltages without a change in the resistance of the heating elements, the performance of the unit (for example, preheat time) may differ at the two voltages.

9.3 Connect the cold water supply to a calibrated low-flow water meter for automatic-fill drip brewers (does not apply to pour-over brewers).

9.4 Install a thermocouple in the supply waterline of the coffee machine to ensure incoming water temperature maintains an average of 70 ± 5°F (21 ± 3°C).

9.5 Position and secure a beaded thermocouple to the center of each warming plate (if applicable). Secure the thermocouple using High Temperature Fiberglass/Silicone Tape, 500°F/ 260°C.

NOTE 5—Recommending the use of 24 gauge wire and hammer the beaded end flat to facilitate better contact with the surface.

9.6 If the machine has an accessible internal tank, monitor the internal water tank temperature, using a beaded thermocouple, by placing it no closer than ½ in. (1.27 cm) from rear wall and bottom of the tank no closer than ¼ in. (0.635 cm) from the heating element. See Fig. 1.

NOTE 6—Some machines may not have a heated tank.

9.7 For single cup (***Type I***) brewers, install a 58 mm double espresso portafilter no more than a ¼ in. (2.54 cm) directly below the dispensing head and make sure that it is level. See Fig. 2. Temperature will be measured using a thermocouple positioned on the inside bottom and center of the portafilter. See Fig. 3.

9.8 For batch (***Type II***) brewers, monitor the temperature in the brew stream by situating a beaded thermocouple at the bottom and in the center of the coffee filter basket. See Fig. 4.

9.9 For single cup (***Type I***) brewers, 11 individual cups large enough to hold the individual brew volumes—typically 6 and 8 oz (177 and 237 mL)—will be used to collect the dispensed coffee after each brew event. Each cup will be weighed before and after being filled to obtain accurate brew volume weight. See Fig. 5.

9.10 For batch (***Type II***) brewers, a standard 64 oz (1.89 L) coffee carafe/decanter will be used for all brew tests (or bigger as needed). Monitor contents by positioning a thermocouple in the geometric center of the carafe. See Fig. 6.

9.11 Allow all apparatus and test material to stabilize for at least 1 hour at 75 ± 5°F (24 ± 3°C) prior to testing to prevent existing temperatures from external environments from skewing data.

NOTE 7—It may be necessary to flush hot water tanks with incoming

FIG. 1 Thermocouple Location for Monitoring Internal Water Tank Temperature

FIG. 2 Portafilter Installation on Single Cup (Type I) Brewer

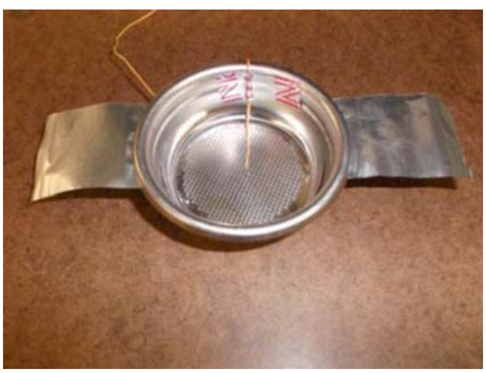

FIG. 3 Thermocouple Location in Portafilter for Monitoring Single Cup (Type I) Brewer Dispensing Temperature

FIG. 4 Thermocouple Location in Coffee Filter Basket for Monitoring Batch (Type II) Brewer Dispensing Temperature

cold water and drain prior to commencing testing if internal temperatures are significantly out of the specified range of 75 ± 5°F (24 ± 3°C).

10. Procedure

10.1 *General:*

10.1.1 While testing the coffee brewer, record the following for each test run: test voltage, ambient temperature, and maximum energy input rate during each test run.

FIG. 5 Sample Test Cups for Single Cup (Type I) Brewer Heavy Use Brewing Energy Test

10.1.2 Prior to performing all tests, confirm that the maximum energy input rate does not exceed 5 % over 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 machine.

10.2 *Maximum Energy Input Rate:*

10.2.1 Ensure that the supply voltage is set to within ±1.0 % of the manufacturer's rated voltage.

10.2.2 For single cup (***Type I***) brewers, initiate a brew cycle and start recording time and energy consumption when the elements are energized and stop recording when the heaters commence cycling (not when the appliance "ready" light or textual digital display comes on). For units with proportional controls, record time and energy consumption while all the heaters are operating at their maximum input and, if applicable, all accessories have been turned on.

NOTE 8—An appliance's ready light is an indication that the unit is up to temperature and not an indication of whether the elements are on or drawing power. It is the intent of this Energy Input Rate procedure to monitor the energy during a continuous period when the elements are energized.

10.2.3 For batch (***Type II***) brewers, drain the water tank (if applicable) and refill with cold water 70 ± 5°F (21 ± 3°C). Turn the brewer and (if applicable) all accessories "on" and at their maximum input setting, and start recording time and energy consumption when the water heating elements are energized and stop recording when the heaters commence cycling (not when the appliance ready light comes on). For units with proportional controls, record time and energy consumption while the heaters are operating at their maximum input.

10.2.4 Confirm that the measured input rate does not exceed more than 5 % over the rated nameplate input (it is the intent of the test procedure herein to evaluate the performance of a coffee brewer at its rated energy input rate). If the maximum measured energy input rate is more than 5 % over the rated input, contact the manufacturer. The manufacturer may make appropriate changes or adjustments to the test coffee brewer or supply another coffee brewer for testing.

10.3 *Preheat:*

FIG. 6 Test Carafe Thermocouple Location for Batch (Type II) Brewer Heavy Use Brewing Energy Test

10.3.1 Determine whether the brewer requires preheating in order to achieve a ready-to-use state. Prior to testing, verify that the brewer and supplemental equipment has stabilized to an average temperature of 75 ± 5°F (24 ± 3°C) before turning the coffee brewer on. If the brewer has an empty reservoir, the cold water temperature entering the brewer will be the initial temperature so long as it is within specified 70 ± 5°F (21 ± 3°C). Otherwise, the ambient temperature will serve as the initial temperature.

NOTE 9—Water will be preheated from the inlet temperature to the final temperature. Therefore preheat rate will be dependent on incoming water temperature and cannot be assumed 75°F.

10.3.2 Turn the coffee brewer on and start recording the time and energy consumption required to preheat the brewer. This is from the time when the unit is turned on until when the brewer achieves a ready-to-use state, as indicated by the brewer's display.

10.4 *"Ready to Brew"(Standby) Energy Rate:*

10.4.1 After the coffee brewer has been turned on and indicated a ready-to-use state, stabilize the brewer for an additional 60 min with all accessories (for example, warmers, lights, etc.) turned on. Monitor energy consumption over a 2-h period while the brewer maintains a ready-to-brew state. This procedure is to be repeated at least three times to obtain the necessary precision.

10.4.2 Repeat the previous step with each accessory turned off. If there is more than one warmer plate, perform tests with one, two, three, or all warmer plates off.

10.5 *"Energy Save Mode" Test ("Low Power Mode" Test):*

10.5.1 For coffee brewers that feature an energy saving mode, preheat then stabilize the coffee brewer for 60 min in the manufacturer's default "energy saver" or "low power" mode. After the stabilization period has elapsed, monitor energy consumption for an additional 2-h period.

10.5.2 At the end of the 2-h period, measure the time and energy required to recover to a ready-to-brew state.

10.6 *Single Cup (**Type I**) Heavy Use Brewing Energy Test:*

10.6.1 For batch (***Type II***) brewers, skip to 10.7.

10.6.2 The brewing test shall be repeated a minimum of three times. Additional test runs may be necessary to obtain the required precision for the reported test results. The reported values of energy consumption, water consumption, and production capacity shall be the average of the three (3) replications (runs).

10.6.3 Set aside 11 single cup coffee packets and weigh each of the packets for each test run. The first brew event will be stabilization and the successive 10 brew events will be counted toward energy efficiency testing.

10.6.4 Preheat the coffee brewer and stabilize in "ready to brew" settings for 60 min. Stabilization is necessary before each test.

10.6.5 Once the 60-min stabilization period has ended, brew the first cup by following the manufacturer instructions. Weigh and record the weight of the full cup and the used individual packet and set aside.

10.6.6 Weigh and record the weight of the full cup and the used individual packet and set aside. Replace the single cup packet in the coffee brewer and begin the next brew event after 2 min of standby allowing the brewer to recover. Once 2 min has elapsed or until the brewer is in a ready-to-brew state, whichever is longer, begin the next brew cycle. As the second load is initiated, start saving data.

10.6.7 Temperature should be monitored for each of the 10 test loads using a thermocouple positioned in the centered bottom of the portafilter basket directly below the dispensing outlet. The maximum temperature reading obtained by the probe in the portafilter basket will be the brew volume temperature.

10.6.8 Repeat 10.6.7 until 10 sequential brew events have been completed and the coffee brewer is recovered. Stop monitoring data and record the total time, energy, and final weights of the dispensed coffee and coffee modules.

10.7 *Batch (**Type II**) Coffee Brewer Heavy Use Brewing Energy Test:*

10.7.1 If the machine is a single cup (***Type I***) coffee brewer, see 10.6.

10.7.2 The heavy use brewing test shall be repeated a minimum of three times. Additional test runs may be necessary to obtain the required precision for the reported test results. The reported values of energy consumption, water consumption and production capacity shall be the average of the replications (runs).

10.7.3 Measure the brew volume by commencing a brew event to serve hot water. Ensure that the container is large enough to hold the dispensed volume.

10.7.4 With all tests, stabilize the coffee brewer at a "ready-to-use" state with all accessories (if applicable) activated for at least 60 min prior to beginning any test. During the 60 min, the coffee brewer should not be in "energy save" or "low power" mode, deactivate automatic settings if necessary.

10.7.5 Prepare the necessary materials needed to commence a brew test. Each test will consist of four consecutive brew events using new filter paper and grounds for each event. Prepare coffee grounds by using a ratio of 0.125 ± 0.005 lb (0.057 ± 0.002 kg) of generic coffee ground in each filter paper for every 64 oz (1.89 L) of delivered brew volume. Record the weights of all empty carafes and coffee filters with grounds.

10.7.6 After the stabilization period, begin the first stabilization brew cycle. Once the brew cycle is complete, remove the filter basket and weigh the saturated grounds and paper filter. Record the weight of the full carafe and set aside.

10.7.7 Allow 1 min of standby time after the brew cycle is completed before the next brew cycle begins. If the coffee brewer has not recovered to a ready-to-brew state after 1 min as indicated by the brewer, wait until the brewer is ready. This extra time will be included in the recovery time.

10.7.8 Replace the basket with a fresh filter and dry grounds and place a separate carafe/decanter in the dispensing position. Begin the second brew cycle and start monitoring time and energy.

10.7.9 When the second brew cycle is complete, record the weight of the full carafe/decanter, and place on the warming plate (if applicable).

10.7.10 Repeat 10.7.8 and 10.7.9 two more times until four full brew events have been completed.

10.7.11 After the final brew cycle is complete, allow the brewer to recover to a "ready to brew" state with all available warming plate positions occupied with full carafes. Stop monitoring data when the brewer has recovered as indicated by the brewer.

11. Calculation and Reporting

11.1 Using Specification F2988 classifications, summarize the physical and operating characteristics of the unit. Use additional text to describe any design 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 Report the voltage for each test.

11.2.3 Report the average ambient temperature for each test.

11.3 *Maximum Energy Input Rate:*

11.3.1 Report the manufacturer's nameplate power rating in kW.

11.3.2 Report the elapsed time (minutes) and energy consumption (kWh) for each test.

11.4 *Preheat Energy Consumption and Time:*

11.4.1 Report the total elapsed time (minutes) and energy consumed (kWh) during the preheat test.

11.4.2 Report the incoming water temperature in °F (°C) and water consumed gal/h (l/h) during the preheat test.

11.5 *Heavy Use Brewing Energy Consumption and Production Capacity:*

11.5.1 Report the total time and energy used to complete the heavy use brewing test.

11.5.2 The production capacity is expressed in gal/hr (L/hr) based on an average of at least three separate test runs.

11.5.3 Report the average incoming water temperature in °F (°C) and water consumed gal/h (l/h) during the heavy use brewing energy tests.

11.5.4 Calculate and report the average energy rate during the heavy use brewing test based on:

$$q_{brew} = \frac{E \times 60}{t} \tag{1}$$

where:

q_{brew} = heavy-use brewing energy rate, kW,
E = energy consumed during the test period, kWh, and
t = test period, min.

11.5.5 Calculate and report the production capacity based on:

$$PC = \frac{V \times 60}{t} = \frac{gal(L)}{h} \tag{2}$$

where:

PC = production capacity of the coffee brewer, gal/h (L/h),
V = total brew volume during the test period, gal (L), and
t = test period, min.

11.6 *Energy Save Mode Energy Rate:*

11.6.1 Report the energy save mode energy consumption based on a minimum of three test runs.

11.6.2 Calculate and report the energy save mode energy rate based on:

$$q_{Esave} = \frac{E \times 60}{t} \tag{3}$$

where:

q_{Esave} = energy save mode energy rate, kW,
E = energy consumed during the test period, kWh, and
t = test period, min.

11.6.3 Report the average tank temperature (if applicable) during the energy save mode energy test.

11.7 *Ready-To-Brew (Standby) Energy Rate:*

11.7.1 Report the average ready-to-brew energy consumption based on a minimum of three test runs.

11.7.2 Calculate and Report the ready-to-brew energy rate based on:

$$q_{ready} = \frac{E \times 60}{t} \tag{4}$$

where:

q_{ready} = ready-to-brew energy rate, kW,
E = energy consumed during the test period including warmer energy, kWh, and
t = test period, min.

11.7.3 Report the average tank temperature (if applicable) during the ready-to-brew test.

12. Precision and Bias

12.1 *Repeatability (within laboratory, same operator and equipment)*—The repeatability of each recorded parameter is being determined.

12.2 *Reproducibility (multiple laboratories)*—The interlaboratory precision of the procedure in this test method for measuring each recorded parameter is being determined.

12.3 *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 recorded.

13. Keywords

13.1 batch brewer; brew volume; coffee; coffee brewer; coffee machine; heavy use energy rate; preheat; ready-to-brew energy rate; single cup; single cup brewer; standby energy rate

ANNEX

(Mandatory Information)

A1. PROCEDURE FOR DETERMINING THE UNCERTAINTY IN REPORTED TEST RESULTS

NOTE A1.1—The procedure described below is based on the procedure for determining the confidence interval for the average of several test results discussed in 6.4.3, ASHRAE Guideline 2–1986 (RA90). It should be applied only to test results that have been obtained within the tolerances prescribed in this test method (for example, with the thermocouples calibrated, and the oven operating within 5 % of rated input during the test run).

A1.1 For the cooking energy efficiency and production capacity procedure, results are reported for the cooking energy efficiency, cooking energy rate, production rate, and cook time. The reporting requirements are summarized in Table A1.1. Each reported result is the average of results from at least three test runs. In addition, the uncertainty in these averages is reported. For each loading scenario, the uncertainty of the cooking energy efficiency and production rate must be no greater than ±10 % before any of the parameters for that scenario can be reported. These parameters are marked with an asterisk (*) in Table A1.1. Therefore, for the heavy load scenario, the uncertainty in both the cooking energy efficiency and production rate must be no greater than ±10 % before any parameter can be reported.

A1.2 The uncertainty in a reported result is a measure of its precision. For example, if the heavy-load production rate for the oven is 60 lb/h, the uncertainty must not be greater than ±6 lb/h. This means that the true production rate is within the interval between 54 lb/h and 66 lb/h. This interval is determined at the 95 % confidence level, which means that there is only a 1 in 20 chance that the true production rate could be outside of this interval.

A1.3 Calculating the uncertainty not only guarantees the maximum uncertainty in the reported results, but also is used to determine how many test runs are necessary to satisfy this requirement. The uncertainty is calculated from the standard deviation of three or more test results and a factor from Table A1.2 which depends on the number of test results used to calculate the average. The percent uncertainty is the ratio of the uncertainty to the average expressed as a percent.

A1.4 *Procedure*:

NOTE A1.2—See A1.5 for an example of applying this procedure.

A1.4.1 *Step 1*—Calculate the average and the standard deviation for the test result (cooking energy efficiency or production rate) using the results of the first three test runs.

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

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

$$Xa_3 = (1/3) \times (X_1 + X_2 + X_3) \quad \text{(A1.1)}$$

where:

Xa_3 = average of the results for three test runs, and

X_1, X_2, and X_3 = results for each test run.

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

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

TABLE A1.1 Reporting and Uncertainty Requirements for Cooking Energy Efficiency Tests

NOTE 1—An asterisk (*) indicates result must have uncertainty less than or equal to ±10 % for reporting.

Loading Scenario	CEE	CER	PR	tc
Heavy	X*	X	X*	X
Light	X*	X	X	X

TABLE A1.2 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

where:

S_3 = standard deviation of the results for three test runs,
A_3 = $(X_1)^2 + (X_2)^2 + (X_3)^2$, and
B_3 = $(1/3) \times (X_1 + X_2 + X_3)^2$.

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

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

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

$$U_3 = C_3 \times S_3$$
$$U_3 = 2.48 \times S_3 \quad \text{(A1.3)}$$

where:

U_3 = absolute uncertainty in the average for three test runs, and
C_3 = uncertainty factor for three test runs (Table A1.2).

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

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

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

where:

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

A1.4.4 *Step 4*—If the percent uncertainty, $\%\ U_3$, is not greater than ±10 % for the cooking energy efficiency (all load scenarios) and production rate (heavy-load scenario only), report the average for all parameters, along with their 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 or heavy-load production rate, proceed to Step 5.

A1.4.5 *Step 5*—Run a fourth test for each loading scenario that resulted in the percent uncertainty being greater than ±10 %.

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

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

$$Xa_4 = (1/4) \times (X_1 + X_2 + X_3 + X_4) \quad \text{(A1.5)}$$

where:

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

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

$$S_4 = (1/\sqrt{3}) \times \sqrt{(A_4 - B_4)} \quad \text{(A1.6)}$$

where:

S_4 = standard deviation of the results for four test runs,
A_4 = $(X_1)^2 + (X_2)^2 + (X_3)^2 + (X_4)^2$, and
B_4 = $(1/4) \times (X_1 + X_2 + X_3 + X_4)^2$.

A1.4.7 *Step 7*—Calculate the absolute uncertainty in the average for each parameter listed in Step 1. Multiply the standard deviation calculated in Step 6 by the uncertainty factor for four test results from Table A1.2.

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

$$U_4 = C_4 \times S_4$$
$$U_4 = 1.59 \times S_4 \quad \text{(A1.7)}$$

where:

U_4 = absolute uncertainty in the average for four test runs, and
C_4 = uncertainty factor for four test runs (Table A1.2).

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

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

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

where:

$\%\ U_4$ = percent uncertainty in the average for four test runs,
U_4 = absolute uncertainty in the 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 no greater than ±10 % for the cooking energy efficiency (all load scenarios) and production rate (heavy-load scenario only), report the average for all parameters, along with their 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 or heavy-load production rate, 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:

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

where:

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

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

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

where:

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

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

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

where:

U_n = absolute uncertainty in the average for n test runs, and
C_n = uncertainty factor for n test runs (Table A1.2).

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

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

where:

$\%\, U_n$ = percent uncertainty in the average for n test runs.

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

$$Xa_n \pm U_n$$

NOTE A1.5—During the course of running these tests, the tester may compute a test result that deviates significantly from the other test results. It may be tempting to discard such a result in an attempt to meet the ±10 % uncertainty requirement. This should be done only if there is some physical evidence that the test run from which that particular result was obtained was not performed according to the conditions specified in this test method (for example, if a thermocouple was out of calibration, the oven's input rate was not within 5 % of the rated input, or a thermocouple slipped out of a potato). To be sure all results were obtained under approximately the same conditions, it is good practice to monitor those test conditions specified in this test method.

A1.5 *Example of Determining Uncertainty in the Average Test Result*:

A1.5.1 Three test runs for the heavy-load cooking scenario yielded the following PR results:

Test	PR
Run No. 1	69.8 lb/h
Run No. 2	75.9 lb/h
Run No. 3	70.3 lb/h

A1.5.2 *Step 1*—Calculate the average and standard deviation of the three test results for the production rate.

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

$$Xa_3 = \left(\frac{1}{3}\right) \times (X_1 + X_2 + X_3)$$
$$Xa_3 = \left(\frac{1}{3}\right) \times (69.8 + 75.9 + 70.3) \quad (A1.13)$$
$$Xa_3 = 72.0 \text{ lb/h}$$

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

$$A_3 = (X_1)^2 + (X_2)^2 + (X_3)^2$$
$$A_3 = (69.8)^2 + (75.9)^2 + (70.3)^2$$
$$A_3 = 15\,575$$
$$B_3 = \left(\frac{1}{3}\right) \times [(X_1 + X_2 + X_3)^2] \quad (A1.14)$$
$$B_3 = \left(\frac{1}{3}\right) \times [(69.8 + 75.9 + 70.3)^2]$$
$$B_3 = 15\,552$$

A1.5.2.3 The new standard deviation for the production rate is as follows:

$$S_3 = (1/\sqrt{2}) \times \sqrt{(15\,575 - 15\,552)} \quad (A1.15)$$
$$S_3 = 3.39 \text{ lb/h}$$

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

$$U_3 = 2.48 \times S_3$$
$$U_3 = 2.48 \times 3.39 \quad (A1.16)$$
$$U_3 = 8.41 \text{ lb/h}$$

A1.5.4 *Step 3*—Calculate the percent uncertainty as follows:

$$\%\, U_3 = (U_3 / Xa_3) \times 100\ \%$$
$$\%\, U_3 = (8.41/72.0) \times 100\ \% \quad (A1.17)$$
$$\%\, U_3 = 11.7\ \%$$

A1.5.5 *Step 4*—Run a fourth test. Since the percent uncertainty for the production rate is greater than ±10 %, the precision requirement has not been satisfied, and an additional test is run in an attempt to reduce the uncertainty. The production rate from the fourth test run was 72.8 lb/h.

A1.5.6 *Step 5*—Recalculate the average and standard deviation for the production rate using the fourth test result.

A1.5.6.1 The new average production rate is as follows:

$$Xa_4 = \left(\frac{1}{4}\right) \times (X_1 + X_2 + X_3 + X_4)$$
$$Xa_4 = \left(\frac{1}{4}\right) \times (69.8 + 75.9 + 70.3 + 72.8) \quad (A1.18)$$
$$Xa_4 = 72.0 \text{ lb/h}$$

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

$$A_4 = (X_1)^2 + (X_2)^2 + (X_3)^2 + (X_4)^2$$
$$A_4 = (69.8)^2 + (75.9)^2 + (70.3)^2 + (72.8)^2$$
$$A_4 = 20\,875$$
$$B_4 = \left(\frac{1}{4}\right) \times [(X_1 + X_2 + X_3 + X_4)^2] \quad (A1.19)$$
$$B_4 = \left(\frac{1}{4}\right) \times [(69.8 + 75.9 + 70.3 + 72.8)^2]$$
$$B_4 = 20\,851$$

A1.5.6.3 The new standard deviation for the production rate is as follows:

$$S_4 = \left(1 / \sqrt{3}\right) \times \sqrt{(20\,875 - 20\,851)}$$
$$S_4 = 2.83 \text{ lb/h} \quad (A1.20)$$

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

$$U_4 = 1.59 \times S_4$$
$$U_4 = 1.59 \times 2.83 \quad (A1.21)$$
$$U_4 = 4.50 \text{ lb/h}$$

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

$$\%\ U_4 = \left(U_4 / Xa_4\right) \times 100\ \%$$
$$\%\ U_4 = (4.50 / 72.2) \times 100\ \% \quad (A1.22)$$
$$\%\ U_4 = 6.2\ \%$$

A1.5.9 *Step 8*—Since the percent uncertainty, % U_4, is less than ±10 %, the average for the production rate is reported along with its corresponding absolute uncertainty, U_4, as follows:

$$\text{PR} = 72.2 \pm 4.50 \text{ lb/h} \quad (A1.23)$$

The production rate can be reported assuming that the ±10 % precision requirement has been met for the corresponding cooking energy efficiency. The cooking energy efficiency and its production rate absolute uncertainty can be calculated following the same steps.