Standard Test Method for Energy Performance of Powered Open Warewashing Sinks[1]

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1. Scope

1.1 This test method evaluates the energy consumption of powered open warewashing sinks. The food service operator can use these tests to evaluate and select a suitable washing device and understand its energy consumption.

1.2 This test method applies to powered open warewashing sinks (powered sinks) with the following characteristics: a large main water sink with electrically powered water pump(s) and multiple high flow water nozzles. The unit may include gas or electric heaters to maintain water temperature. These powered sinks are designed to run for predetermined cycle duration and accommodate pots and pans of various shapes and sizes as well as cooking utensils. They are intended for stand alone use and require little supervision. The powered sink will be tested for the following (where applicable):

1.2.1 Maximum energy input rate (10.2),

1.2.2 Preheat energy consumption and duration (10.3),

1.2.3 Idle energy rate (10.4),

1.2.4 Pilot energy rate, if applicable (10.5), and

1.2.5 Washing cycle energy consumption (10.6).

NOTE 1—This test method applies only to the powered portion of the unit. Other compartments (sanitizing, rinsing, and so forth) are not evaluated.

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]

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

2.2 *ANSI Standard:*

2000 International Fuel Gas Code[3]

2.3 *ASHRAE Documents:*

ASHRAE Guideline 2 (RA90) Engineering Analysis of Experimental Data[4]

ASHRAE 1993 Fundamentals Handbook[4]

3. Terminology

3.1 *Definitions:*

3.1.1 *powered open warewashing sink, or powered sink, n*—an all-purpose, stainless steel water sink with electrically powered water pump(s) and multiple high flow water nozzles designed for cleaning pots, pans, and utensils. The main washing sink holds 60 to 100 gal of heated water. The unit may or may not feature a scrapper sink, rinse tank, sanitizing tank, scrap table, or a drain table, or both.

3.1.2 *test method, n*—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 test results.

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *energy input rate, n*—peak rate at which a powered sink consumes energy (Btu/h or kW (kJ/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] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

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

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3.2.2 *idle energy rate, n*—the rate of energy consumed (Btu/h or kW (kJ/h)) by the powered sink while holding or maintaining a water-filled wash sink at the 115°F (46°C) setpoint.

3.2.3 *pilot energy rate, n*—average rate of energy consumption (Btu/h) by a powered sink's continuous pilot (if applicable).

3.2.4 *preheat energy, n*—amount of energy consumed by the powered sink while preheating the wash sink water from 70 ± 5°F (21 ± 3°C) to 115°F (46°C), with the control(s) set to a calibrated 115°F (46°C).

3.2.5 *preheat rate, n*—average rate (°F/min) at which the powered sink's water is heated from 70 ± 5°F (21 ± 3°C) to 115°F (46°C), with the control(s) set to a calibrated 115°F (46°C).

3.2.6 *preheat time, n*—time required for the powered sink water to preheat from 70 ± 5°F (21 ± 3°C) to 115°F (46°C), with the control(s) set to a calibrated 115°F (46°C).

3.2.7 *washing energy, n*—amount of energy consumed (Btu or kWh (kJ)) during the powered sink's washing cycle.

3.2.8 *washing energy rate, n*—average rate of energy consumption (Btu/h or kW (kJ/h)) during the powered sink's washing cycle.

4. Summary of Test Method

4.1 The powered sink under test is connected to the appropriate metered energy supply. The measured energy input rate is determined and checked against the rated input before continuing with testing.

4.2 The amount of cold (70 ± 5°F (21 ± 3°C)) water required to fill the main water sink to capacity is measured.

4.3 The amount of energy and time required to preheat the powered sink's wash sink from 70 ± 5°F (21 ± 3°C) to 115°F (46°C) is determined.

4.4 The rate of idle energy consumption is determined with the powered sink set to maintain 115°F (46°C) and the pump motor(s) switched off.

4.5 Pilot energy rate is determined, when applicable, for gas powered sinks.

4.6 Washing cycle energy consumption is characterized for two different starting water temperatures: 70°F (21°C) and 115°F (46°C).

5. Significance and Use

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

5.2 Preheat energy and time can be useful to food service operators to manage power demands and to know how quickly the powered sink can be ready for operation when filled with cold water.

NOTE 2—It is typically recommended that powered sinks be filled with hot water prior to use. This test is useful for operations that have a limited supply of domestic hot water and would need to use cold water to fill the sink to capacity.

5.3 Idle energy rate and pilot energy rate can be used to estimate energy consumption during standby periods.

5.4 Washing cycle energy consumption can be used by the food service operator to estimate energy consumption during operating periods.

6. Apparatus

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

6.2 *Calibrated Exposed Junction Thermocouple Probes,* with a range from 50 to 200°F (10 to 93°C), with a resolution of 0.2°F (0.1°C) and an uncertainty of 0.5°F (0.3°C), for measuring the average temperature of the sink water, heating element temperature, and ambient air temperature.

6.3 *Gas Meter,* for measuring the gas consumption of the powered sink (if applicable), shall have a resolution of at least 0.01 ft^3 (0.0003 m^3) and a maximum uncertainty no greater than 1 % of the measured value for any demand greater than 2.2 ft^3/h (0.06 m^3/h). If the meter is used for measuring the gas consumed by pilot lights, it shall have a resolution of at least 0.01 ft^3 (0.0003 m^3) and have a maximum uncertainty no greater than 2 % of the measured value.

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

6.5 *Primary Supply,* water heating system capable of supplying water at 115 ± 5°F (46 ± 3°C), as required by the powered sink.

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

6.7 *Temperature Sensor,* for measuring natural gas temperature in the range of 50 to 100°F (10 to 37.8°C), with a resolution of 0.5°F (0.3°C) and an uncertainty of ±1°F (0.6°C).

6.8 *Thermocouple Probe,* industry standard type T or type K thermocouples capable of immersion with a range of 50 to 200°F (10 to 93°C) and an uncertainty of ±1°F.

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

7. Reagents and Materials

7.1 *Water,* to fill the water sink shall meet the manufacturer's specifications for quality and hardness.

7.2 *Powered Sink Detergent,* to be added to the water shall meet power washer manufacturer's specifications for type and amount. Otherwise, the detergent shall be a standard liquid type with labeling specifying use in power washers and four ounces (4 oz) shall be added to the primary wash tank for all tests.

8. Sampling and Test Units

8.1 *Powered Sink*—A representative production model with heater shall be selected for performance testing.

9. Preparation of Apparatus

9.1 Install the appliance in accordance with the manufacturer's instructions and under a dedicated hood if necessary. Both sides of the powered sink shall be a minimum of 6 in. (305 mm) from any wall, side partition, or other operating appliance. The associated heating or cooling system shall be capable of maintaining an ambient temperature of 75 ± 5°F (24 ± 3°C) within the testing environment when the exhaust ventilation system or the powered sink, or both, are operating.

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

9.3 For an electric powered sink, confirm (while the powered sink elements are energized) that the supply voltage is within ±2.5 % of the operating voltage specified by the manufacturer (see Note 3). Record the voltage for each test. Pump and heater energy consumption shall be separately monitored and reported for all tests.

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

9.4 For a gas powered sink, adjust (during maximum energy input) the gas supply pressure downstream from the powered sink's pressure regulator to within ±2.5 % of the operating manifold pressure specified by the manufacturer. Make adjustments to the powered sink following the manufacturer's recommendations for optimizing combustion.

9.5 Install a temperature sensor to record ambient temperatures of the test room. Measure the height of the powered sink. The sensor shall be placed 24 in. (610 mm) away from the front of the powered sink and at a height of half the powered sink's height.

9.6 Firmly attach eight thermocouple probes evenly along the front and rear sides of the water sink only. For the front wall, two thermocouple probes shall be located (⅓ × height of the water fill line from the bottom), above the bottom of the sink (⅓ × width of the sink), and one from the right and one from the left wall. Two more thermocouples shall be located (⅔ × height of the water fill line from the bottom), above the bottom of the sink (⅓ × width of the sink), and one from the right and one from the left wall. These steps shall be repeated exactly for the rear wall. See Fig. 1. For example, for a water sink with a front wall dimension of 18 in. to the fill line and 48 in. from left to right shall have two thermocouples located 6 in. from the bottom at 16 in. from either side and two thermocouples 12 in. from the bottom and 16 in. from either side. Repeat for rear wall. (See Fig. 1 for thermocouple location illustration.)

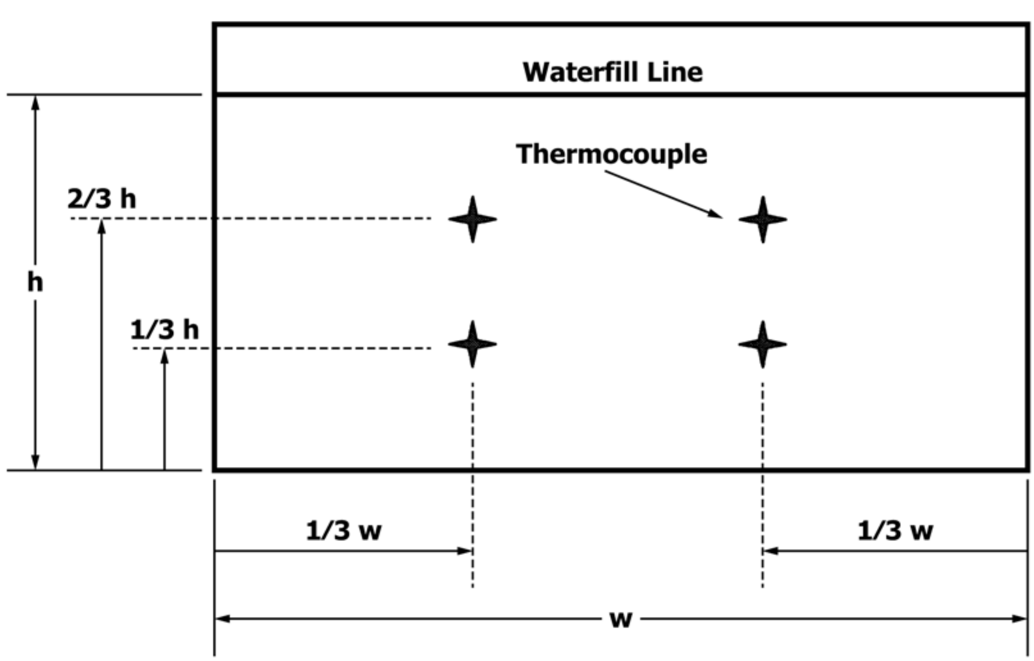

FIG. 1 Diagram of Thermocouple Placement per 9.6

10. Procedure

10.1 *General:*

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

10.1.1.1 Higher heating value,

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

10.1.1.3 Measured gas temperature,

10.1.1.4 Measured gas pressure,

10.1.1.5 Barometric pressure, and

10.1.1.6 Energy input rate during or immediately prior to test.

NOTE 4—For a gas appliance, the quantity of heat (energy) generated by the complete combustion of the fuel is known as the heating value, heat of combustion, or calorific value of that fuel. For natural gas, this heating value varies according to the constituents of the gas. It is measured in Btu/ft^3. The heating value shall be obtained during testing and used in the determination of the energy input to the appliance. Using a calorimeter or gas chromatograph in accordance with accepted laboratory procedures is the preferred method for determining the higher heating value of gas supplied to the powered sink under test. It is recommended that all testing be performed with gas having a higher heating value of 1000 to 1075 Btu/ft^3. The use of "bottle" natural gas with a certified heating value within the specified 1000 to 1075 Btu/ft^3 (37 300 to 40 100 kJ/m^3) range is an acceptable alternative.

10.1.2 For gas powered sinks, record all electric energy consumption along with gas energy for all tests, with the exception of the energy input rate test (see 10.2).

10.1.3 For electric powered sinks, the following shall be obtained and recorded for each run of every test.

10.1.3.1 Voltage while heating element is energized,

10.1.3.2 Electricity consumed where applicable, and

10.1.3.3 Measured energy input rate during test run.

10.1.4 For electric powered sinks, separately record and report pump and heater energy consumption.

10.1.5 For each test run, confirm that the peak input rate is within ±5 % of the rated nameplate input. If the difference is greater than 5 %, testing shall be terminated and the manufacturer contacted. The manufacturer may make appropriate changes or adjustments to the washer.

10.1.6 For each test run, the correct amount and type of detergent must be present and thoroughly mixed with the main tank water according to the manufacturer's directions (see 7.2).

10.2 *Maximum Energy Input Rate:*

10.2.1 Fill the powered sink to the indicated fill line with 70 ± 5°F (21 ± 3°C) water. Measure and record the amount of water required to fill the powered sink to the manufacturer's recommended fill level.

10.2.2 Turn the powered sink on with the temperature control(s) set to the maximum setting.

10.2.3 Monitor the consumption of energy for 15 min after the unit is turned on (or all burners have ignited). If the preheat time is less than 15 min (that is, the burners or elements have commenced cycling in that time), monitor the energy consumption and time after the unit is turned on until the first burner or element cycles off.

10.2.4 Confirm that the measured input rate or power (Btu/h for a gas powered sink and kW for an electric powered sink) is within 5 % of the rated nameplate input or power. Testing shall be terminated and the manufacturer contacted if the difference is greater than 5 %. The manufacturer may make appropriate changes or adjustments to the unit or choose to supply an alternative unit for testing. It is the intent of the test procedure herein to evaluate the performance of a powered sink at its rated energy input rate.

10.3 *Preheat Energy Consumption and Duration:*

NOTE 5—The preheat test should be conducted prior to powered sink operation on the day of the test.

10.3.1 Starting with the unit at room temperature, fill the main water sink with 70 ± 5°F (21 ± 3°C) water. Monitor the average temperature of the water as washer is filled. If the average temperature is not 70 ± 5°F (21 ± 3°C), then hot and cold water may be mixed to attain this starting temperature. Furthermore, all other tanks connected/adjacent to the primary wash tank must be kept empty. Record the time required to fill the sink.

10.3.2 If an optional sink cover is provided with the unit, it must be used to cover the wash tank during all tests.

10.3.3 Record the temperature of the water in the sink. Start the preheat and activate the pump. Begin monitoring energy consumption and time as soon as the heating elements are energized. Preheat is judged complete when the average water temperature reaches 115°F (46°C). Record energy consumption, elapsed time, and final water temperature when the heating elements cycle off.

10.4 *Idle Energy Rate:*

10.4.1 If an optional sink cover is provided with the unit, it must be used to cover the wash tank during all tests.

10.4.2 Allow powered sink to idle for at least 30 min after preheat.

10.4.3 With the pump motor(s) turned off, commence monitoring the elapsed time and energy consumption of the powered sink as it maintains operating temperature for a minimum of 2 h.

10.5 *Pilot Energy Rate (Gas Models with Standing Pilots):*

10.5.1 Where applicable, set the gas valve that controls gas supply to the appliance at the "pilot" position. Otherwise, set the powered sink temperature controls to the "off" position, if adjustable.

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

10.5.3 Record the gas reading after a minimum of 8 h of pilot operation.

10.6 *Washing Cycle Energy Consumption:*

10.6.1 Conduct the washing cycle test a minimum of three times for each starting temperature without any objects in the main water sink. If an optional sink cover is provided with the unit, it must be used to cover the wash tank during all tests. Additional test runs may be necessary to obtain the required precision for the reported test results (see Annex A1).

10.6.2 Starting with the unit at room temperature, fill the main water sink with 70 ± 5°F (21 ± 3°C) water. Monitor the average temperature of the water as washer is filled. If the average temperature is not 70 ± 5°F (21 ± 3°C), then hot and cold water may be mixed to attain this starting temperature.

10.6.3 Start wash cycle (heating element and pump on) and begin recording all temperatures, relevant energy consumption values, and heating element on time for 2 h. Stop all pumping and record all relevant data.

10.6.4 Drain the wash sink and allow the powered sink to stabilize at room temperature for a minimum of 2 h.

10.6.5 Fill the main water sink with 115 ± 5°F (46 ± 3°C) water. Monitor the average temperature of the water as washer is filled. If the average temperature is not 115 ± 5°F (46 ± 3°C), then hot and cold water may be mixed to attain this starting temperature.

10.6.6 Start wash cycle (heating element and pump on) and begin recording all temperatures, relevant energy consumption values, and heating element on time for 2 h. Stop all pumping and record all relevant data.

10.6.7 Perform runs #2 and #3 by repeating 10.6.2 through 10.6.6. Follow the procedure in Annex A1 to determine whether more than three test runs are required.

11. Calculation and Report

11.1 *Test Powered Sink*—Summarize the physical and operating characteristics of the powered sink. Use additional text to describe any design characteristics (for example, tank insulation, covers, adjacent sinks, etc.) that may facilitate the audience's interpretation of the test results.

11.2 *Apparatus and Procedure*—Confirm that the testing apparatus conformed to all of the specifications in Section 9. Describe any deviations from those specifications.

11.3 *Gas Energy Calculations:*

11.3.1 For gas powered sinks, report electric energy consumption for all tests, with the exception of the energy input rate test (see 10.2).

11.3.2 Calculate the energy consumed based on:

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

where:

E_{gas} = energy consumed by the powered sink,
HV = higher heating value,
= energy content of gas measured at standard conditions, Btu/ft^3 (kJ/m^3),
V = actual volume of gas corrected for temperature and pressure at standard conditions, ft^3 (m^3), and
= $V_{meas} \times T_{cf} \times P_{cf}$

where:

V_{meas} = measured volume of gas, ft^3 (m^3),
T_{cf} = temperature correction factor,

$$= \frac{\text{absolute standard gas temperature, °R (°K)}}{\text{absolute actual gas temperature, °R (°K)}}$$

$$= \frac{\text{absolute standard gas temperature, °R (°K)}}{[\text{gas temp °F} + 459.67], \text{°R (°K)}}$$

P_{cf} = pressure correction factor,

$$= \frac{\text{absolute actual gas pressure, psia (kPa)}}{\text{absolute standard pressure, psia (kPa)}}$$

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

NOTE 6—Absolute standard gas temperature and pressure used in this calculation should be the same values used for determining the higher heating value. Standard conditions using Practice D3588 are 14.696 psia (101.33 kPA) and 60°F (519.67°R, (288.71°K)).

11.4 *Maximum Energy Input Rate:*

11.4.1 Report the manufacturer's rated energy input (nameplate) in kW.

11.4.2 Calculate and report the maximum energy input rate (kW) based on the energy consumed by the powered sink during the preheat period using the following:

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

where:

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

The conversion factor is 60 min/h.

11.4.3 Report the amount of 70 ± 5°F (21 ± 3°C) water required to fill the powered sink to the manufacturer's recommended level.

11.5 *Preheat Energy and Time:*

11.5.1 Report the preheat energy consumption (kWh) and the preheat time (min), as determined in 10.3.

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

11.5.3 Generate a graph showing powered sink tank water temperature versus time for the preheat period including any temperature overshoot.

11.6 *Idle Energy Rate*—Calculate and report the idle energy rate (kW) based on the energy consumption of the powered sink during the idle period determined in 10.4 using the following:

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

where:

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

11.7 *Pilot Energy Rate*—Calculate and report the pilot energy rate (Btu/h) based on:

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

where:

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

11.8 *Washing Cycle Energy Consumption:*

11.8.1 Report the total washing cycle time. Separately report the energy consumed by the heaters and the pump motor during the cold-start washing cycle test.

11.8.2 Calculate and report the baseline temperature test energy rate (kW) based on the energy consumption of the powered sink during the baseline temperature heatup period determined in 10.6 using the following:

$$q_{cold-start} = \frac{E \times 60}{t} \quad (5)$$

where:

$q_{cold\text{-}start}$ = washing cycle energy rate, starting with the water at 70°F (21°C), kW,
E = energy consumed during the test period, kWh, and
t = test period, min.

11.8.3 Calculate the heating element duty cycle based on the heating element on time versus the test duration of the wash cycle in Procedure 10.6 using the following:

$$duty\ cycle_{cold-start} = \frac{t_{he}}{t_{washcycle}} \times 100\,\% \quad (6)$$

where:

$duty\ cycle_{cold\text{-}start}$ = duty cycle of heating element during the cold-start washing energy test, percent (%),
t_{he} = total time heating element is cycled on, min, and
$t_{washcycle}$ = total wash cycle duration, min.

11.8.4 Generate a graph showing powered sink tank water temperature and energy input rate $q_{cold\text{-}start}$ versus time for the test period.

11.8.5 Report the total washing cycle time. Separately report the energy consumed by the heaters and the pump motor during the optimum washing cycle test.

11.8.6 Calculate and report the optimum temperature energy rate (kW) based on the energy consumption of the powered sink during the optimum temperature heatup period determined in 10.6 using the following:

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

where:

$q_{optimum}$ = washing cycle energy rate, starting with the water at 115°F (46°C), kW,
E = energy consumed during the test period, kWh, and
t = test period, min.

11.8.7 Calculate the heating element duty cycle based on the heating element on time versus the test duration of the wash cycle in Procedure 10.6 using the following:

$$duty\ cycle_{optimum} = \frac{t_{he}}{t_{washcycle}} \times 100\,\% \quad (8)$$

where:

$duty\ cycle_{optimum}$ = duty cycle of heating element during the optimum washing energy test, percent (%),
t_{he} = total time heating element is cycled on, min, and
$t_{washcycle}$ = total wash cycle duration, min.

11.8.8 Generate a graph showing powered sink tank water temperature and energy input rate $q_{optimum}$ versus time for the test period.

12. Precision and Bias

12.1 *Precision:*

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

12.1.1.1 For the washing energy rate results, the percent uncertainty in each result has been specified to be no greater than ±10 % based on at least three test runs.

12.1.1.2 The repeatability of each reported parameter is being determined. The repeatability of the cleanability test cannot be determined because of the descriptive nature of the test result.

12.1.2 *Reproducibility*—The interlaboratory precision of the procedures in these test methods for measuring each reported parameter is being determined.

12.2 *Bias*—No statement can be made concerning the bias of the procedures in these test methods because there are no accepted reference values for the parameters reported.

13. Keywords

13.1 duty cycle; energy consumption; powered sink; powered warewashing sink; test method

ANNEX

(Mandatory Information)

A1. PROCEDURE FOR DETERMINING THE UNCERTAINTY IN REPORTED TEST RESULTS

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

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

A1.2 The uncertainty in a reported result is a measure of its precision. If, for example, the washing cycle energy consumption for the appliance is 15.0 kWh, the uncertainty must not be greater than ±1.5 kWh. Thus, the true washing cycle energy consumption is between 13.5 and 16.5 kWh. This interval is determined at the 95 % confidence level, which means that there is only a 1 in 20 chance that the true washing cycle energy consumption could be outside of this interval.

A1.3 Calculating the uncertainty not only guarantees the maximum uncertainty in the reported results, but is also used to determine how many test runs are needed to satisfy this requirement. The uncertainty is calculated from the standard deviation of three or more test results and a factor from Table A1.1, which lists the number of test results used to calculate the average. The percent uncertainty is the ratio of the uncertainty to the average expressed as a percent.

A1.4 *Procedure* :

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

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

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

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

TABLE A1.1 Uncertainty Factors

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

where:

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

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

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

where:

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

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

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

A1.4.2 *Step 2*—Calculate the absolute uncertainty in the average for 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 A1.1.

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

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

$$U_3 = 2.48 \times S_3$$

where:

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

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

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 average for three test runs,
U_3 = absolute uncertainty in average for three test runs, and
Xa_3 = average of three test runs.

A1.4.4 *Step 4*—If the percent uncertainty, $\%U_3$, is not greater than ±10 % for the washing cycle energy consumption, report the average for these 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 washing cycle energy consumption, proceed to Step 5.

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

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

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

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

where:

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

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

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

where:

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

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 A1.1.

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

$$U_4 = C_4 \times S_4 \quad (A1.7)$$

$$U_4 = 1.59 \times S_4$$

where:

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

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

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

$$\%U_4 = (U_4/Xa_4) \times 100\,\% \quad (A1.8)$$

where:

$\%U_4$ = percent uncertainty in average for four test runs,
U_4 = absolute uncertainty in average for four test runs, and
Xa_4 = average of four test runs.

A1.4.9 *Step 9*—If the percent uncertainty, $\%U_4$, is not greater than ±10 % for the washing cycle energy consumption, report the average for these 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 washing cycle energy consumption, 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:

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

where:

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

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

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

where:

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

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

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

where:

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

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

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

where:

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

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

$$Xa_n \pm U_n$$

NOTE A1.5—The researcher may compute a test result that deviates significantly from the other test results. Such a result should be discarded only if there is some physical evidence that the test run was not performed according to the conditions specified in this test method. For example, a thermocouple was out of calibration, the appliance's input capacity was not within 5 % of the rated input, or the other parameters were not within specification. To assure that all results are obtained under approximately the same conditions, it is good practice to monitor those test conditions specified in this method.

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

A1.5.1 Three test runs for the cold-start scenario yielded the following washing cycle energy consumption results:

Test	PC
Run #1	16.9 kWh
Run #2	17.1 kWh
Run #3	15.5 kWh

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

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

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

$$Xa_3 = \left(\frac{1}{3}\right) \times (16.9 + 17.1 + 15.5),$$

$$Xa_3 = 16.5 \text{ lb/h}$$

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

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

$$A_3 = (16.9)^2 + (17.1)^2 + (15.5)^2,$$

$$A_3 = 818.3$$

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

$$B_3 = \left(\frac{1}{3}\right) \times [(16.9 + 17.1 + 15.5)^2],$$

$$B_3 = 816.7$$

A1.5.2.3 The new standard deviation is as follows:

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

$$S_3 = 0.87 \; kWh$$

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

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

$$U_3 = 2.48 \times 0.87,$$

$$U_3 = 2.16 \text{ kWh}$$

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

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

$$\%U_3 = (2.16/16.5) \times 100\,\%,$$

$$\%U_3 = 13.1\,\%$$

A1.5.5 *Step 4*—Run a fourth test. Since the percent uncertainty for the washing cycle energy consumption is greater than ±10 %, the precision requirement has not been satisfied. An additional test is run in an attempt to reduce the uncertainty. The washing cycle energy consumption from the fourth test run was 16.2 kWh.

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

A1.5.6.1 The new average is as follows:

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

$$Xa_4 = \left(\frac{1}{4}\right) \times (16.9 + 17.1 + 15.5 + 16.2),$$

$$Xa_4 = 16.4 \text{ kWh}$$

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

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

$$A_4 = (16.9)^2 + (17.1)^2 + (15.5)^2 + (16.2)^2,$$

$$A_4 = 1080.7$$

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

$$B_4 = \left(\frac{1}{4}\right) \times [(16.9 + 17.1 + 15.5 + 16.2)^2],$$

$$B_4 = 1079.1$$

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

$$S_4 = (1/\sqrt{3}) \times \sqrt{(1080.7 - 1079.1)}, \quad \text{(A1.20)}$$

$$S_4 = 0.73 \text{ kWh}$$

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

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

$$U_4 = 1.59 \times 0.73,$$

$$U_4 = 1.16 \text{ kWh}$$

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

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

$$\%U_4 = (1.16/16.4) \times 100\,\%,$$

$$\%U_4 = 7.1\,\%$$

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

$$\text{washing cycle energy consumption}: 16.4 \pm 1.16 \text{ kWh} \quad \text{(A1.23)}$$

APPENDIX

(Nonmandatory Information)

X1. RESULTS REPORTING SHEETS

Manufacturer ____
Model ____
Date _______________
Test Reference Number (optional) _______________

Test Powered Sink
Description of operational characteristics ____
____
____
____
____

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

Energy Input Rate
Test Voltage (V) ________
Gas Heating Value (Btu/ft^3 (kJ/m^3)) ________
Measured (Btu/h (kJ/h) or kW) ________
Rated (Btu/h (kJ/h) or kW) ________
Percent Difference between Measured and Rated (%) ________
Pump Motor Energy Rate (kW) ________
Water Capacity (gal (L)) ________

Preheat Energy and Time (see Fig X1.1 for Preheat Curve)
Test Voltage (V) ________
Gas Heating Value (Btu/ft^3 (kJ/m^3)) ________
Starting Temperature (°F (°C)) ________
Energy Consumption (Btu (kJ/h) or kWh) ________
Duration (min) ________
Preheat Rate (°F/min (°C/min)) ________

Idle Energy Rate
Test Voltage (V) ________
Gas Heating Value (Btu/ft^3 (kJ/m^3)) ________
Idle Energy Rate (Btu/h (kJ/h) or kW) ________
Electric Energy Rate (kW, gas powered sinks only) ________

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

Washing Cycle Energy Consumption
Cold-Start (see Fig. X1.2 for Cold-Start Washing Cycle Temperature Curve)
Test Voltage (V) ________
Gas Heating Value (Btu/ft^3 (kJ/m^3)) ________
Total Washing Cycle Time (min) ________
Washing Energy (Btu (kJ) or kWh) ________
Pump Energy (kWh) ________
Washing Energy Rate (Btu/h (kJ/h) or kW) ________
Duty Cycle (%) ________

Optimum (see Fig. X1.3 for Optimum Washing Cycle Temperature Curve)
Test Voltage (V) ________
Gas Heating Value (Btu/ft^3 (kJ/m^3)) ________
Total Washing Cycle Time (min) ________
Washing Energy (Btu (kJ) or kWh) ________
Pump Energy (kWh) ________
Washing Energy Rate (Btu/h (kJ/h) or kW) ________
Duty Cycle (%) ________

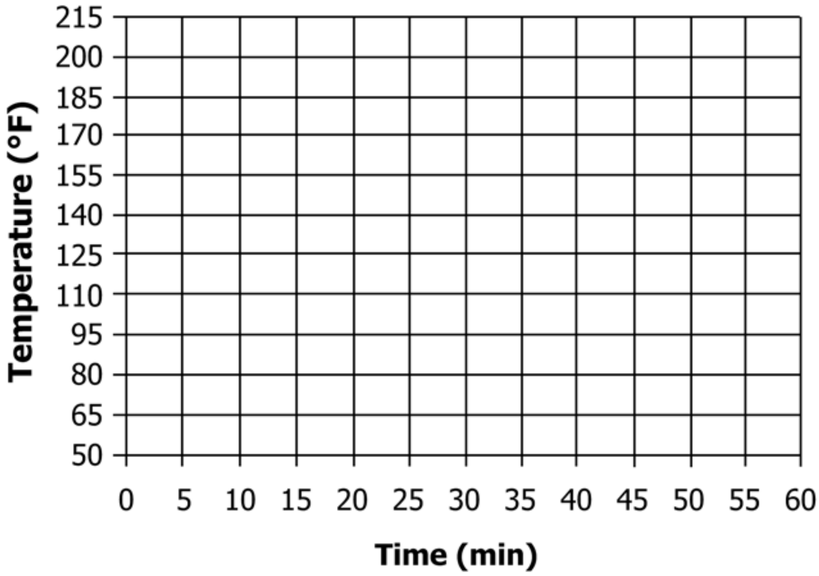

FIG. X1.1 Preheat Curve

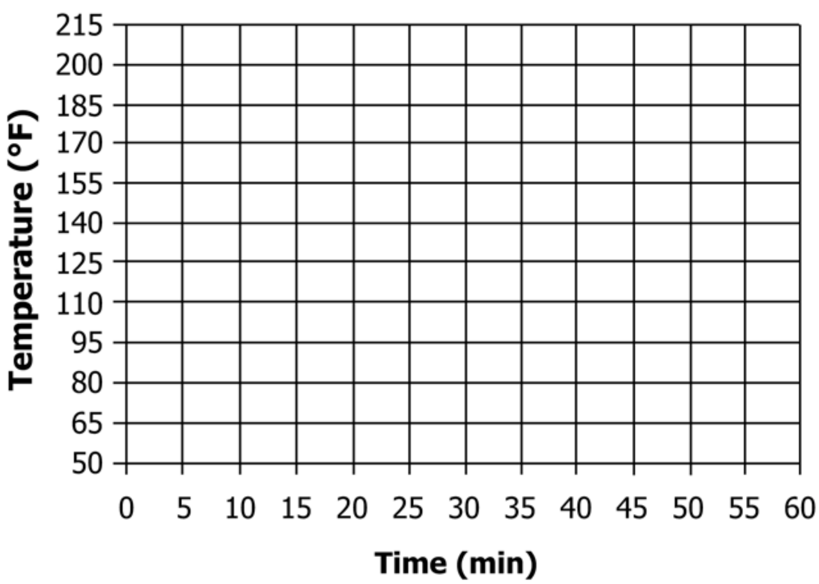

FIG. X1.2 Cold-Start Washing Cycle Temperature Curve

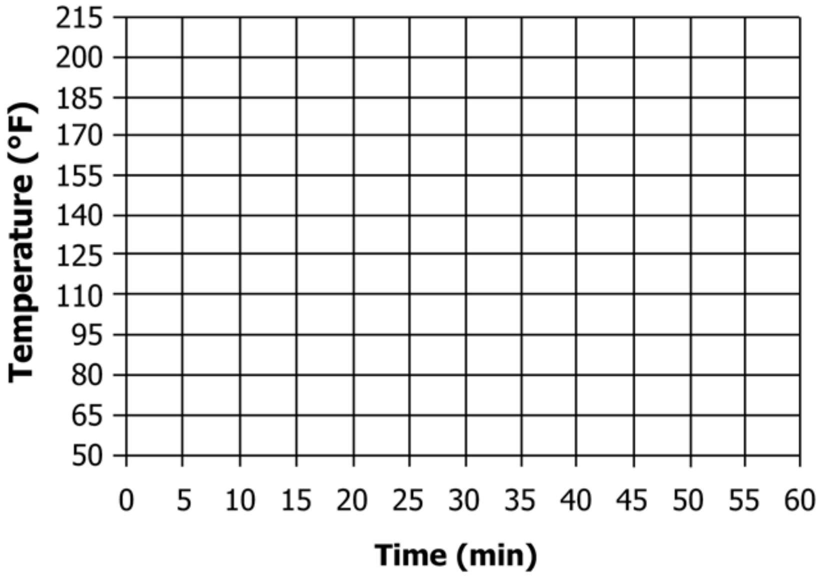

FIG. X1.3 Optimum Washing Cycle Temperature Curve

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