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Designation: ~~E2618 – 09~~ E2618 – 13

Standard Test Method for Measurement of Particulate Emissions and Heating Efficiency of ~~Outdoor~~ Solid Fuel-Fired Hydronic Heating Appliances[1]

This standard is issued under the fixed designation E2618; 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 applies to wood-fired or automatically fed biomass burning hydronic heating ~~appliances, which the manufacturer specifies for outdoor installation or in structures not normally occupied by humans.~~ appliances. These appliances transfer heat to the indoor environment through circulation of a liquid heat exchange media such as water or a water-antifreeze mixture.

1.2 The test method simulates hand loading of seasoned cordwood or fueling with a specified biomass fuel and measures particulate emissions and delivered heating efficiency at specified heat output rates based on the appliance's rated heating capacity.

1.3 Particulate emissions are measured by the dilution tunnel method as specified in Test Method E2515. Delivered efficiency is ~~measured~~determined by ~~determining~~ measurement of the usable heat output (determined through measurement of the flow rate and temperature change of water circulated through a heat exchanger external to the ~~appliance~~appliance) and ~~determining~~ the heat input (determined from the mass of dry fuel burned and its higher heating ~~value.~~value). Delivered efficiency does not attempt to account for pipeline loss.

1.4 Products covered by this test method include both pressurized and non-pressurized heating appliances intended to be fired with wood or automatically fed biomass fuels. These products are hydronic heating appliances which the manufacturer specifies for outdoor ~~installation or in structures not normally occupied by humans.~~ or indoor installation. They are often connected to ~~an indoor~~ a heat exchanger by insulated pipes ~~buried in the ground~~ and normally include a pump to circulate heated liquid. They are used to heat structures such as homes, barns, and greenhouses and can heat domestic hot water, spas, or swimming pools.

1.4.1 Hydronic heating systems that incorporate a high mass heat storage system that is capable of storing the entire heat output of a standard fuel load are tested by the procedure specified in Annex A1. Systems that incorporate high mass heat storage capable of storing a portion of the output from a standard fuel load are tested by the procedure specified in Annex A2.

1.5 Distinguishing features of products covered by this standard include:

1.5.1 Manufacturers specify ~~outdoor installation or installation in structures not normally occupied by humans.~~indoor or outdoor installation.

1.5.2 A firebox with an access door for hand loading of fuel or a hopper and automated feed system for delivery of particulate fuel such as wood pellets or solid biomass fuel to a burn pot or combustion chamber.

1.5.3 Typically a thermostatic control device that controls combustion air supply or fuel delivery, or both, to maintain the liquid in the appliance within a predetermined temperature range provided sufficient fuel is available in the firebox or hopper.

1.5.4 A chimney or vent that exhausts combustion products from the appliance.

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

1.6.1 *Exception*—Metric units are used in 13.1, 13.4.3, Tables 4-6, and A1.11.6.

1.7 *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.*

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[1] This test method is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.54 on Solid Fuel Burning Appliances.

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2. Referenced Documents

2.1 *ASTM Standards:*[2]

D4442 Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials

E631 Terminology of Building Constructions

E711 Test Method for Gross Calorific Value of Refuse-Derived Fuel by the Bomb Calorimeter (Withdrawn 2011)[3]

E2515 Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel

2.2 *Other Standards:*

CAN/CSA-B415.1-2010 Performance Testing of Solid-Fuel-Burning Heating Appliances[4]

ASME Pressure Vessel Code[5]

EN303–5 Pressure Vessel Code[6]

NIST Traceable Methods[7]

2.3 *Other Documents:*[7]

Monograph 175 Temperature-Electromotive Force Reference Functions and Tables for the Letter-Designated Thermocouple Types Based on the ITS-90

3. Terminology

3.1 *Definitions*—Definitions are in accordance with Terminology E631, unless otherwise indicated.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *burn rate*—the rate at which test fuel is consumed in an appliance measured in kilograms or pounds of fuel (dry basis) per hour.

3.2.2 *delivered efficiency*—the percentage of heat available in a test fuel charge that is delivered to a simulated heating load as specified in this test method. This test does not account for jacket losses or for transfer line losses which will vary with actual application.

3.2.3 *firebox*—the chamber in the appliance in which the test fuel charge is placed and combusted.

3.2.4 *hydronic heating*—a heating system in which a heat source supplies energy to a liquid heat exchange media such as water that is circulated to a heating load and returned to the heat source through pipes.

3.2.5 *manufacturer's rated heat output capacity*—the value in Btu/h (MJ/h) that the manufacturer specifies a particular model of hydronic heating appliance is capable of supplying at its design capacity as verified by testing, in accordance with Section 12.

3.2.6 *overall efficiency, also known as stack loss efficiency*—The efficiency for each test run as determined using the CSA B415.1-2010 Stack Loss Method (SLM)

3.2.7 *test fuel charge*—a full load of fuel as specified in Section 12 placed in the appliance at the start of the emission test run or the mass of fuel consumed by automatically fed appliance during a test run.

3.2.8 *test run*—an individual emission test which encompasses the time required to consume the mass of the test fuel charge.

3.2.9 *thermostatic control*—a control device that opens, closes or modulates a circuit to control the rate of fuel consumption in response to the temperature of the heating media in the heating appliance.

4. Summary of Test Method

4.1 *Dilution Tunnel*—Emissions are determined using the "dilution tunnel" method specified in Test Method E2515. The flow rate in the dilution tunnel is maintained at a constant level throughout the test cycle and accurately measured. Samples of the dilution tunnel flow stream are extracted at a constant flow rate and drawn through high efficiency filters. The filters are dried and weighed before and after the test to determine the particulate emissions catch and this value is multiplied by the ratio of tunnel flow to filter flow to determine the total emissions produced in the test cycle.

4.2 ~~*Delivered Efficiency*—~~*Efficiency:* ~~The efficiency test procedure takes advantage of the fact that this type of appliance delivers heat through circulation of the heated liquid (water) from the appliance to a remote heat exchanger and back to the appliance. Measurements of the water temperature difference as it enters and exits the heat exchanger along with the measured flow rate allow for an accurate determination of the useful heat output of the appliance. The input is determined by weight of the test fuel charge,~~

[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] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from Canadian Standards Association (CSA), 5060 Spectrum Way, Mississauga, ON L4W 5N6, Canada, http://www.csa.ca.

~~**FIG. 1 Heat Exchanger Schematic**~~

[5] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Three Park Ave., New York, NY 10016-5990, http://www.asme.org.

[6] Available from European Committee for Standardization (CEN), Avenue Marnix 17, B-1000, Brussels, Belgium, http://www.cen.eu.

[7] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.gov.

~~adjusted for moisture content, multiplied by the higher heating value. Additional measurements of the appliance weight and temperature at the beginning and end of a test cycle are used to correct for heat stored in the appliance.~~

4.2.1 *Delivered Efficiency*—The efficiency test procedure takes advantage of the fact that this type of appliance delivers heat through circulation of the heated liquid (water) from the appliance to a remote heat exchanger and back to the appliance. Measurements of the water temperature difference as it enters and exits the heat exchanger along with the measured flow rate allow for an accurate determination of the useful heat output of the appliance. The input is determined by weight of the test fuel charge, adjusted for moisture content, multiplied by the higher heating value. Additional measurements of the appliance weight and temperature at the beginning and end of a test cycle are used to correct for heat stored in the appliance.

4.2.2 *Overall Efficiency*—Overall Efficiency (SLM) is determined using the CSA B415.1-2010 Stack Loss Method for data quality assurance purposes.

4.3 *Operation*—Appliance operation is conducted on a hot-to-hot test cycle meaning that the appliance is brought to operating temperature and a coal bed is established prior to the addition of the test fuel charge and measurements are made for each test fuel charge cycle. The measurements are made under constant heat draw conditions within predetermined ranges. No attempt is made to modulate the heat demand to simulate an indoor thermostat cycling on and off in response to changes in the indoor environment. Four test categories are used. These are:

4.3.1 *Category I*—A heat output of 15 % or less of Manufacturer's Rated Heat Output Capacity.

4.3.2 *Category II*—A heat output of 16 to 24 % of Manufacturer's Rated Heat Output Capacity.

4.3.3 *Category III*—A heat output of 25 to 50 % of Manufacturer's Rated Heat Output Capacity.

4.3.4 *Category IV*—Manufacturer's Rated Heat Output Capacity.

5. Significance and Use

5.1 The measurement of particulate matter emission rates is an important test method widely used in the practice of air pollution control.

5.1.1 These measurements, when approved by federal or state agencies, are often required for the purpose of determining compliance with regulations and statutes.

5.1.2 The measurements made before and after design modifications are necessary to demonstrate the effectiveness of design changes in reducing emissions and make this standard an important tool in manufacturer's research and development programs.

5.2 Measurement of heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

5.3 This is a laboratory method and is not intended to be fully representative of all actual field use. It is recognized that users of hand-fired wood burning equipment have a great deal of influence over the performance of any wood-burning appliance. Some compromises in realism have been made in the interest of providing a reliable and repeatable test method.

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6. Apparatus

6.1 *Scale*—A platform scale capable of weighing the appliance under test and associated parts and accessories when completely filled with water to an accuracy of ±1.0 lb (±0.5 kg).

6.2 *Heat Exchanger*—A water-to-water heat exchanger capable of dissipating the expected heat output from the system under test.

6.3 *Water Temperature Difference Measurement*—~~Thermocouples or a thermopile installed in thermowells~~ A Type -T "special limits" thermopile with a minimum of five pairs of junctions shall be used to measure the temperature difference in water entering and leaving the heat exchanger. The temperature difference measurement ~~shall have an uncertainty of ±0.50ºF (±0.25ºC).~~uncertainty of this type of thermopile is equal to or less than ±0.50ºF (±0.25ºC). Other temperature measurement methods may be used if the temperature difference measurement uncertainty is equal to or less than ±0.50ºF (±0.25ºC).

6.4 *Load Side Water Flow Meter*—A ~~totalizing type~~ water flow meter ~~with a resolution of 0.1 gal (0.025 L) and an accuracy of 0.5 % of volume recorded or a flow meter with~~ shall be installed in the inlet to the load side of the heat exchanger. The flow meter shall have an accuracy of ~~±0.01 gal/min (±0.0025 L/min).~~±1 % of measured flow.

6.4.1 *Optional Appliance Side Water Flow Meter*—A water flow meter with an accuracy of ±1 % of the flow rate is recommended but not required to monitor appliance side water flow rate to the heat exchanger.

6.5 *Recirculation Pump*—~~Circulating~~ Optional circulating pump used during test to prevent stratification of liquid being heated.

6.6 *Water Temperature Measurement*—Thermocouples or other temperature sensors to measure the water temperature at the inlet and outlet of the load side of the heat exchanger. Must meet the calibration requirements specified in 10.1.

6.7 *Wood Moisture Meter*—Calibrated electrical resistance meter capable of measuring test fuel moisture to within 2 % moisture content. Must meet the calibration requirements specified in 10.4.

6.8 *Flue Gas Temperature Measurement*—Must meet the requirements of CSA B415.1-2010, Clause 6.2.2.

6.9 *Test Room Temperature Measurement*—Must meet the requirements of CSA B415.1-2010, Clause 6.2.1.

6.10 *Flue Gas Composition Measurement*—Must meet the requirements of CSA B415.1-2010, Clauses 6.3.1 through 6.3.3.

7. Hazards

7.1 These tests involve combustion of solid fuel and substantial release of heat and products of combustion. The heating system also produces large quantities of very hot water and the potential for steam production and system pressurization. Pressurized (closed system) appliances must include an appropriately rated American Society of Mechanical Engineers (ASME) pressure relief device and a pressure vessel that complies with the ASME Pressure Vessel ~~Code.~~ Code or EN303-5 pressure vessel code. Alternatively, a pressure vessel may be installed open to the atmosphere with a stand pipe if allowed by the manufacturer's installation instructions. Appropriate precautions must be taken to protect personnel from burn hazards and respiration of products of combustion.

8. Sampling, Test Specimens, and Test Appliances

8.1 Test specimens shall be supplied as complete appliances including all controls and accessories necessary for installation in the test facility. A full set of specifications and design and assembly drawings shall be provided when the product is to be placed under certification of a third-party agency. The manufacturer's written installation and operating instructions are to be used as a guide in the set up and testing of the appliance.

9. Preparation of Apparatus

9.1 The appliance is to be placed on a scale capable of weighing the appliance fully loaded with a resolution of ±1.0 lb (±0.5 kg).

9.2 The appliance shall be fitted with the type of chimney recommended or provided by the manufacture and extending to 15 ± 0.5 ft (4.6 ± 0.15 m) from the upper surface of the scale. If no flue or chimney system is recommended or provided connect the appliance to a flue of a diameter equal to the flue outlet of the appliance and extending 15 ± 0.5 ft (4.6 ± 0.15 m) from the top of the scale. For flue systems not provided by the manufacturer, the flue section from the appliance flue collar to 8 ± 0.5 ft (2.44 ± 0.15 m) above the scale shall be single wall stove pipe and the remainder of the flue shall be double wall insulated Class A chimney.

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9.3 ~~The manufacturer may request that a recirculation pump be installed between connections at the top and bottom of the appliance to minimize thermal stratification. The pump shall not be installed in such a way as to change or affect the flow rate between the appliance and the heat exchanger. As an alternative, the testing lab may employ a thermocouple tree to determine the average unit temperature.~~ *Optional Equipment Installation:*

9.3.1 The manufacturer may request that a recirculation pump be installed between connections at the top and bottom of the appliance to minimize thermal stratification. The pump shall not be installed in such a way as to change or affect the flow rate between the appliance and the heat exchanger.

9.3.2 If the manufacturer specifies that a thermal control valve or other device be installed and set to control the return water temperature to a specific set point, the valve or other device shall be installed and set per the manufacturer's written instructions.

9.4 Prior to filling the tank, weigh and record the appliance mass.

~~9.5 Plumb the unit to a water-to-water heat exchanger with sufficient capacity to draw off heat at the maximum rate anticipated. Route hoses and electrical cables and instrument wires in a manner that does not influence the weighing accuracy of the scale as indicated by placing dead weights on the platform and verifying the scale's accuracy.~~

9.5 ~~Locate thermocouples to measure the water temperature at the inlet and outlet of the heat exchanger in the supply line and return line from the cooling water system. Also install a calibrated water flow meter. If temperature differences are expected to be small, a differential thermopile should be used to measure the water delta-T. The water flow meter is to be installed on the cooling water inlet side of the heat exchanger so that it will operate at the same temperature as its calibration. Place the heat exchanger in a box with 2 in. (50 mm) of expanded polystyrene (EPS) foam insulation surrounding it to minimize heat losses form the heat exchanger. The reported efficiency and heat output rate shall be based on measurements made on the load side of the system. (See Fig. 1 and Fig. 2.)~~ *Heat Exchanger Temperature, Differential Temperature and Water Flow Instrumentation:*

9.5.1 Plumb the unit to a water-to-water heat exchanger with sufficient capacity to draw off heat at the maximum rate anticipated. Route hoses and electrical cables and instrument wires in a manner that does not influence the weighing accuracy of the scale as indicated by placing dead weights on the platform and verifying the scale's accuracy.

9.5.2 Locate thermocouples to measure the water temperature at the inlet and outlet of the load side of the heat exchanger.

9.5.3 Install a thermopile meeting the requirements of 6.3 to measure the water temperature difference between the inlet and outlet of the load side of the heat exchanger.

9.5.4 Install a calibrated water flow meter in the heat exchanger load side supply line. The water flow meter is to be installed on the cooling water inlet side of the heat exchanger so that it will operate at the temperature at which it is calibrated.

9.5.5 Place the heat exchanger in a box with 2 in. (51 mm) of expanded polystyrene (EPS) foam insulation surrounding it to minimize heat losses from the heat exchanger.

9.5.6 The reported efficiency and heat output rate shall be based on measurements made on the load side of the heat exchanger. (See Fig. 1.)

9.6 Temperature instrumentation shall be installed in the output and return lines from the appliance (supply side). The average of the outlet and return water temperature on the supply side of the system shall be considered the average appliance temperature for calculation of heat storage in the appliance (TF_{avg} and TI_{avg}). Installation of a water flow meter in the appliance (supply) side of the system is optional.

9.7 Fill the system with water. Determine the total weight of the water in the appliance when the water is circulating. Verify that the scale indicates a stable weight under operating conditions. Make sure air is purged properly.

10. Calibration and Standardization

10.1 *Temperature Sensors*—Temperature measuring equipment shall be calibrated ~~to~~ before initial use and at least semi-annually thereafter. Calibrations shall be in compliance with National Institute of Standards and Technology (NIST) ~~traceable standards at least once every six months.~~Monograph 175, Temperature-Electromotive Force Reference Functions and Tables for the Letter-Designated Thermocouple Types Based on the ITS-90.

10.2 *Water Flow Meter*—The heat exchanger load side water flow meter shall be calibrated within the flow range used for the test run using NIST Traceable ~~methods at least once every six months. At the conclusion of~~ Methods. Verify the calibration of the water flow meter before and after each test run ~~that accuracy of the water meter shall be verified by collecting water~~ by comparing the water flow rate indicated by the flow meter to the mass of water collected from the outlet of the ~~load side of the system for a timed interval and weighing the water collected.~~ heat exchanger over a timed interval. Volume of the collected water shall be determined based on the water density calculated from Eq 10~~The flow rate in gallons per minute~~ , using the water temperature measured at the flow meter. The uncertainty in the verification procedure used shall be 1 % or less. The water flow rate determined by the collection and weighing method shall be within ~~±0.5 % of that~~ 1 % of the flow rate indicated by the water flow meter.

10.3 *Scales*—The scales used to weigh the appliance and test fuel charge shall be calibrated using NIST Traceable ~~methods~~Methods at least once every six months.

10.4 *Moisture Meter*—The moisture meter shall be calibrated per the manufacturer's instructions and checked before each use.

11. Conditioning

11.1 Prior to testing, the ~~non-catalytic~~ appliance is to be operated for a minimum of ~~10~~48 h using a medium heat draw rate. ~~Catalytic units shall be operated for a minimum of 50 h using a medium heat draw rate.~~ The pre-burn for the first test can be included as part of the conditioning requirement. If conditioning is included in pre-burn, then the appliance shall be aged with fuel

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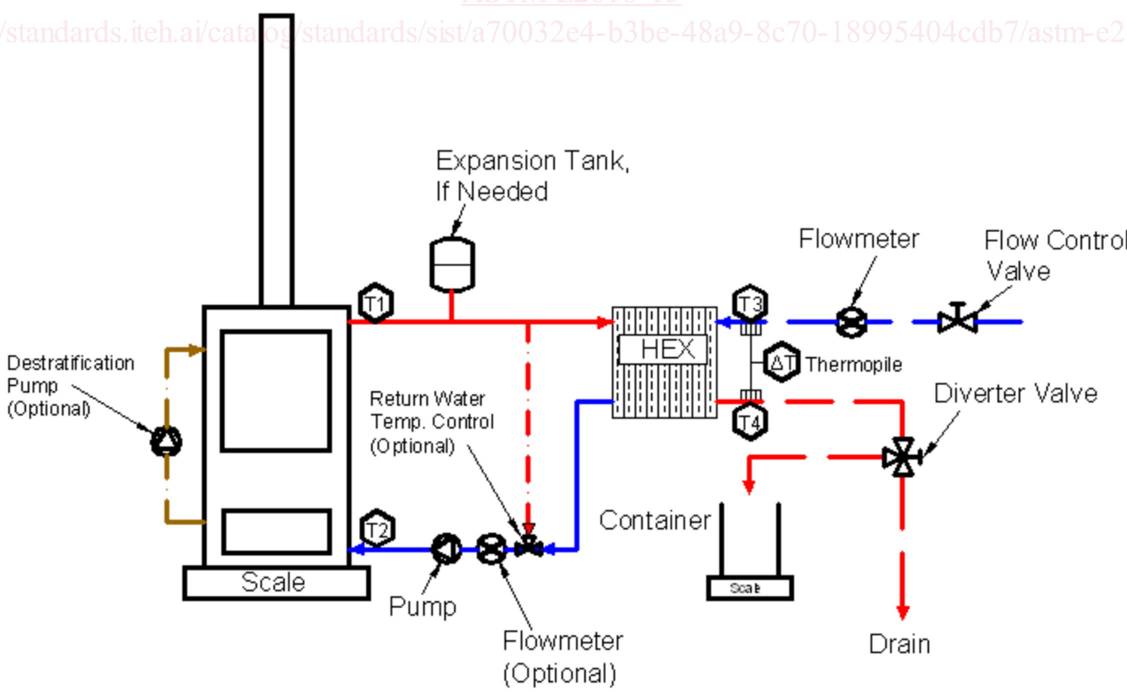

Illustrated appliance pump location and flow path through the appliance are generic and may vary based on the unit being tested.

FIG. ~~2~~1 Set-Up Schematic

meeting the specifications outlined in 12.2 with a moisture content between 18 and 28 % on a dry basis. Operate the appliance at a medium burn rate (Category II or III) for at least 10 h for non-catalytic appliances and 50 h for catalytic appliances. Record and report hourly flue gas exit temperature data and the hours of operation. The aging procedure shallIt is acceptable that the conditioning procedure may be conducted and documented by a testing the manufacturer prior to submission of the test appliance to a testing laboratory or it may be conducted and documented by the testing laboratory.

12. Procedure

12.1 *Appliance Installation*—Assemble the appliance and parts in conformance with the manufacturer's written installation instructions. Clean the flue with an appropriately sized, wire chimney brush before each certification test series.

12.2 *Cordwood Fueled Appliances:*

12.2.1 *Fuel*—Test fuel charge fuel shall be white or red oak cordwood 18 to 28 % moisture content–dry basis. Cord wood used shall be split on at least one face, have a maximum cross sectional dimension of 10 in. (254 mm) and a minimum cross sectional dimension, measured at the widest point on a line perpendicular to the longest cross section dimension, of 3 in. (76 mm). Only cordwood pieces that are free of decay, fungus, and loose bark shall be used. All pieces selected shall weigh between 4.4 and 22 lb (2 to 10 kg). For each test fuel load at least 80 % of the load weight shall be comprised of fuel pieces weighing between 8 and 18 lb (3.6 and 8.2 kg). Piece length shall be 20 ± 4 in. (490 ± 102 mm). (See Fig. 3.) Pieces are to be placed in the firebox parallel to the longest firebox dimension or in the direction specified in the manufacturer's printed operating instructions. When loading test fuel loads, no effort shall be made to stack fuel pieces in a particular manner.

12.2.1 *Moisture Content*—*Fuel Properties:* Determine the test fuel moisture content with a calibrated electrical resistance moisture meter. Determine fuel moisture for each fuel piece by averaging at least three moisture meter readings, one from each of three sides, measured parallel to the wood grain. Measure the moisture content within 2 to 3 in. (50 to 75 mm) of each end and at the center of each piece. Average all the readings for each fuel piece in the test fuel charge. Penetration of the moisture meter insulated electrodes shall be at least 0.75 in. (19 mm). Measure the moisture content within a 4 h period prior to the test run.

12.2.1.1 *Fuel Species and Properties*—The test fuel charge shall be comprised of any species of cordwood with a specific gravity in the range of 0.60 to 0.73 based on oven dry weight and volume. Refer to Table 1 for examples of some fuel species that typically meet the specific gravity requirement. Other fuel species may be used if they meet the specific gravity requirement. Only cordwood pieces that are free of decay, fungus and loose bark shall be used.

12.2.1.2 *Test Fuel Moisture*—Using a fuel moisture meter as specified in 6.7 of the test method, determine the fuel moisture for each test fuel piece used for the test fuel load by averaging at least five fuel moisture meter readings measured parallel to the wood grain. Penetration of the moisture meter insulated electrodes for all readings shall be 1/4 the thickness of the fuel piece or 3/4 in. (19 mm), whichever is greater. One measurement from each of three sides shall be made at approximately 3 in. from each end and the center. Two additional measurements at approximately 1/3 of the fuel piece thickness shall be made centered between the other three locations. Each individual moisture content reading shall be in the range of 18 to 28 % on a dry basis. The average moisture content of each piece of test fuel shall be in the range of 19 to 25 %. Moisture shall not be added to previously dried fuel pieces except by storage under high humidity conditions and temperature up to 100ºF. Fuel moisture shall be measured within 4 h of using the fuel for a test.

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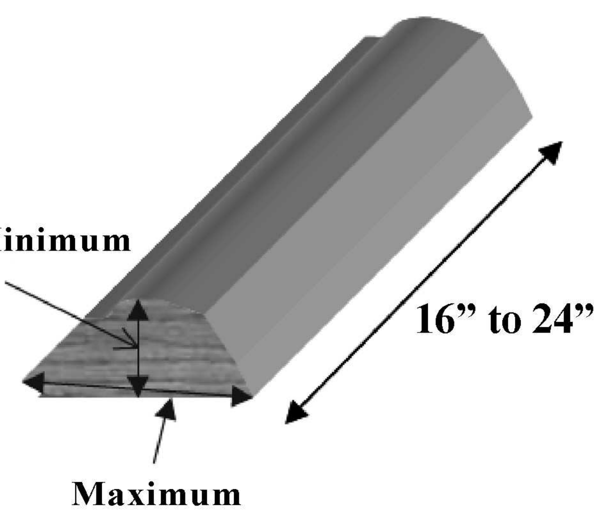

FIG. 32 Cord Wood Cordwood Fuel

TABLE 1 Specific Gravity of Commercially Important Species of Wood Based on Oven-Dry Weight and Oven-Dry Volume

Species	Specific Gravity
Ash, white	0.63
Beech	0.67
Birch, sweet	0.71
Birch, yellow	0.65
Elm, rock	0.67
Maple, hard (black)	0.60
Maple, hard (sugar)	0.67
Oak, red	0.66
Oak, white	0.71
Pine, Southern, longleaf	0.64

NOTE 1—Once split cordwood pieces have dried to an average moisture content that is near the top of the allowable moisture content range, it has been found that to maintain the fuel pieces within the allowable moisture content range, storage at a relative humidity of 95 % or higher and temperature of 90 to 100ºF is necessary. In addition, storage at these conditions for a period of several months helps achieve a more uniform moisture content throughout the fuel pieces and thus improves the accuracy of the moisture content measurement.

12.2.2 *Firebox Volume*—Determine the firebox volume in cubic feet. Firebox volume shall include all areas accessible through the fuel loading door where firewood could reasonably be placed up to the horizontal plane defined by the top of the loading door. A drawing of the firebox showing front, side and plan views or an isometric view with interior dimensions shall be provided by the manufacturer and verified by the laboratory. Calculations for firebox volume from computer aided design (CAD) software programs are acceptable and shall be included in the test report if used. If the firebox volume is calculated by the laboratory the firebox drawings and calculations shall be included in the test report.

12.2.3 *Test Fuel Charge*—Test fuel charges shall be determined by multiplying the firebox volume by 10 lb (4.54 kg), or a higher load density as recommended by the manufacturer's printed operating instructions, of wood (as used wet weight) per cubic foot. Select the number of pieces of fuel that most nearly match this target ~~weight.~~ weight using Table 2 and Fig. 2 as a guide. When the manufacturer's printed instructions specify fuel loading to a specific level, the firebox shall be loaded with fuel as specified in 12.2.1 to the level indicated and the weight of the fuel load recorded. This weight shall then be divided by the firebox volume as determined in accordance with 12.2.3 and the resulting loading density shall be reported. If this loading density is less than 10 lb/ft^3 (160 kg/m^3), all tests shall be run with fuel load densities of 10 lb/ft^3 (160 kg/m^3) even though this could require loading to a level higher than indicated in the manufacturer's instructions.

12.2.4 *Sampling Equipment*—Prepare the sampling equipment as defined by Test Method E2515.

12.2.5 *Appliance Start-Up*—The appliance shall be fired with wood fuel of any species, size and moisture content at the laboratories discretion to bring it up to operating temperature. Operate the appliance until the water is heated to the upper operating control limit and has cycled at least two times. Then remove all unburned fuel, zero the scale, and verify the scales accuracy using dead weights.

12.2.6 *Pretest Burn Cycle*—Reload appliance with ~~oak~~ fuel wood meeting the requirements of 12.2.1 and allow it to burn down to the specified coal bed weight. Pretest burn cycle fuel charge weight shall be within ±10 % of the test fuel charge weight. At least ~~2~~1 h prior to starting the test run, adjust water flow to the heat exchanger to establish the target heat draw for the test. For the first test run the heat draw rate shall be equal to the manufacturer's rated heat output capacity.

12.2.7 *Allowable Adjustments*—Fuel addition or subtractions, and coal bed raking shall be kept to a minimum but are allowed up to 15 min prior to the start of the test run. For the purposes of this method, coal bed raking is the use of a metal tool (poker) to stir coals, break burning fuel into smaller pieces and dislodge fuel pieces from positions of poor combustion. Record all adjustments to and additions or subtractions of fuel, and any other changes to the appliance operations that occur during pretest ignition period. During the 15-min period prior to the start of the test run, the appliance loading door shall not be open more than a total of 1 min. Coal bed raking is the only adjustment allowed during this period.

12.2.8 *Coal Bed Weight*—The appliance is to be loaded with the test fuel charge when the coal bed weight is between 10 and 20 % of the test fuel charge weight. Coals may be raked as necessary to level the coal bed or position coals as recommended in the manufacturer's printed operating instructions but may only be raked and stirred once between 15 to 20 min prior to the addition of the test fuel charge.

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TABLE 2 Correlation of Cordwood Wood Pieces with Appliance Firebox Volume

Firebox Volume ft^3 (m^3)	Cross-section of piece in. (mm) Minimum	Cross-section of piece in. (mm) Maximum	Minimum weight of piece lb (kg)	Maximum weight of piece lb (kg)	80 % piece weight range lb (kg)	Number of pieces
<4 (<0.11)	2 (51)	6 (152)	2.2 (1)	13.2 (6)	3 to 11 (1.5 to 5)	4 to 7
4 to <10 (0.11 to <0.28)	2.5 (64)	8 (203)	4.4 (2)	17.6 (8)	6.6 to 15.4 (3 to 7)	5 to 10
10 to <20 (0.28 to <0.56)	3 (76)	10 (254)	6.6 (3)	22 (10)	8.8 to 19.8 (4 to 9)	8 to 15
≥20 (≥0.56)	3 (77)	12 (305)	8.8 (4)	26.5 (12)	8.8 to 22 (4 to 10)	>12

12.2.9 *Test Cycle*—For all test runs, the return water temperature to the hydronic heater must be equal to or greater than 120°F. Aquastat or other heater output control device settings that are adjustable shall be set using manufacturer specifications, either as factory set or in accordance with the owner's manual, and shall remain the same for all burn categories. Complete a test run in each heat output rate category, as follows:

12.2.9.1 *Test Run Start*—Once the appliance is operating normally and the pretest coal bed weight has reached the target value in accordance with ~~12.2.9~~12.2.8, tare the scale, start all sampling systems and load the full test charge into the appliance. Time for loading shall not exceed 5 min. The actual weight of the test fuel charge shall be measured and recorded within 30 min prior to loading. ~~Record all data at intervals of 10 min or less. Record water flow and temperature data and monitor the average heat output rate. If the heat output rate gets close to the upper or lower limit of the target range adjust the water flow through the heat exchanger to compensate. Make changes as infrequently as possible while maintaining the target heat output rate. The first test run shall be conducted at the Category IV heat output rate to validate that the appliance is capable of producing the manufacturer's rated heat output capacity.~~

(1) Record all water temperatures, differential water temperatures and water flow rates at time intervals of 1 min or less.

(2) Record particulate emissions data per the requirements of Test Method E2515.

(3) Record data needed to determine Overall Efficiency (SLM) per the requirements of CSA B415.1-2010 Clauses 6.2.1, 6.2.2, 6.3, 8.5.7, 10.4.3 (a), 10.4.3 (f), and 13.7.9.3

(a) Measure and record the test room air temperature in accordance with the requirements of Clauses 6.2.1, 8.5.7 and 10.4.3 (g).

(b) Measure and record the flue gas temperature in accordance with the requirements of Clauses 6.2.2, 8.5.7 and 10.4.3 (f).

(c) Determine and record the Carbon Monoxide (CO) and Carbon Dioxide (CO_2) concentrations in the flue gas in accordance with Clauses 6.3, 8.5.7 and 10.4.3 (i) and (j).

(d) Measure and record the test fuel weight per the requirements of Clauses 8.5.7 and 10.4.3 (h).

(e) Record the test run time per the requirements of Clause 10.4.3 (a).

(4) Record water flow and temperature data and monitor the average heat output rate. If the heat output rate gets close to the upper or lower limit of the target range (±5 %) adjust the water flow through the heat exchanger to compensate. Make changes as infrequently as possible while maintaining the target heat output rate. The first test run shall be conducted at the Category IV heat output rate to validate that the appliance is capable of producing the manufacturer's rated heat output capacity.

12.2.9.2 *Test Fuel Charge Adjustment*—It is acceptable to adjust the test fuel charge (that is, reposition) once during a test run if more than 60 % of the initial test fuel charge weight has been consumed and more than 10 min have elapsed without a measurable (1 lb ~~(0. 5 kg)~~ (0.5 kg) or 1 % of the test fuel load weight, whichever is greater) weight change while the operating control is in the demand mode. The time used to make this adjustment shall be less than 60 s.

12.2.9.3 *Test Run Completion*—The test run is completed when the remaining weight of the test fuel charge is 0.0 lb (0.0 kg). End the test run when the scale has indicated a test fuel charge weight of 0.0 lb (0.0 kg) or less for 30 s. At the end of the test run, stop the particulate sampling and record the run time and all final measurement values.

12.2.10 *Heat Output Capacity Validation*—The first test run must produce a heat output rate that is within 10 % of the manufacturer's rated heat output capacity (Category IV). If the appliance is not capable of producing a heat output within these limits, the manufacturer's rated heat output capacity is considered not validated and testing is to be terminated. In such cases, the tests may be continued using the heat output capacity as measured as the Manufacturer's Rated Heat Output Capacity if requested by the manufacturer.

12.2.11 *Additional Test Runs*—Using the Manufacturer's Rated Heat Output Capacity as a basis, conduct a test for additional heat output categories as specified in 4.3. It is not required to run these tests in any particular order.

12.2.12 *Alternative Heat Output Rate for Category I*—If an appliance cannot be operated in the Category I heat output range due to stopped combustion two test runs shall be conducted at heat output rates within Category II. When this is the case, the weightings for the weighted averages indicated in 14.1.14 shall be the average of the Category I and II weightings and shall be applied to both Category II results. Appliances that are not capable of operation within Category II (<25 % of maximum) cannot be evaluated by this test method.

12.2.13 *Stopped Fuel Combustion*—Evidence that an appliance cannot be operated at a Category I heat output rate due to stopped fuel combustion shall include documentation of two or more attempts to operate the appliance in burn rate Category I and fuel combustion has stopped prior to complete consumption of the test fuel charge. Stopped fuel combustion is evidenced when an elapsed time of 60 min or more has occurred without a measurable (1 lb (0.5 kg) or 1 % of the test load weight, whichever is greater) weight change in the test fuel charge while the appliance operating control is in the demand mode. Report the evidence and the reasoning used to determine that a test in burn rate Category I cannot be achieved. For example, two unsuccessful attempts to operate at an output rate of 10 % of the rated output capacity are not sufficient evidence that burn rate Category I cannot be achieved.

12.2.14 *Appliance Overheating*—Appliances shall be capable of operating in all heat output categories without overheating to be rated by this test method. Appliance overheating occurs when the rate of heat withdrawal from the appliance is lower than the rate of heat production when the unit control is in the idle mode. This condition results in the water in the appliance continuing to increase in temperature well above the upper limit setting of the operating control. Evidence of overheating includes: 1 h or more

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of appliance water temperature ~~increase~~ greater than 15°F (8°C) above the upper temperature set-point of the operating control, exceeding the temperature limit of a safety control device (independent from the operating control), boiling water in a non-pressurized system or activation of a pressure or temperature relief valve in a pressurized system.

12.2.15 *Additional Test Runs*—The testing laboratory may conduct more than one test run in each of the heat output categories specified in 4.3. If more than one test run is conducted at a specified heat output rate, the results from at least two thirds of the test runs in that heat output rate category shall be used in calculating the weighted average emission rate (see 14.1.14). The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the weighted average emission rate.

12.3 *Automatically Fueled Appliances:*

12.3.1 Appliances designed to burn automatically fed fuels such as wood pellets, shelled corn, wood chips or other biomass shall be tested using the fuel or fuels specified in the manufacturer's operating instructions.

12.3.2 *Operation*—The fuel used shall have representative samples taken and tested for higher heating value in accordance with Test Method E711 and for moisture content by the oven drying method (Test Methods D4442, Method A or B). Sufficient fuel for the tests shall be placed in a hopper on a scale that allows for measurement of the mass of fuel consumed during the test runs to an accuracy of ±1 lb (±0.5 kg). The unit shall be set up and operated in accordance with the ~~manufacture's~~manufacturer's instructions. A heat exchanger as specified in Section 9 shall be used to draw heat from the appliance at the rates specified for the categories specified in 4.3. The unit shall be operated for a minimum of 2 h at the specified heat output rate prior to starting the measurement phase of the test.

12.3.3 *Measurement Phase*—Record the weight of the fuel in the hopper after the unit has been in operation at the specified heat draw rate for ~~2~~1 h. Start the emissions measurement sampling train and data collection as required in Test Method E2515. Continue operation for a minimum of 4 h. At the end of the test period, stop the sampling train and record the final weight of the fuel in the hopper. Calculate the emissions, efficiency and heat output rate as specified in Section 13 using the mass of fuel consumed and the higher heating value for the fuel. Repeat this procedure for each heat output rate category. If more ~~that~~than one fuel type is specified, repeat the entire rating procedure for each fuel type.

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13. Calculation of Results

13.1 *Symbols:*

E_T = total particulate emissions measured during a full test cycle, grams (from Test Method E2515 Eq. 10)

$E_{g/MJ}$ = emission rate in grams per mega joule of heat output

$E_{lb/MMBtu\ Output}$ = emissions rate in pounds per million Btu of heat output

$E_{lb/MMBtu\ Input}$ = emissions rate in pounds per million Btu of heat input

$E_{g/kg}$ = emissions factor in grams per kilogram of dry fuel burned

$E_{g/h}$ = emission ~~factor~~rate in grams per hour

ASTM E2618-13

E_{avg} = weighted average emissions in pounds per million Btu of heat output

HHV = higher heating value of fuel = ~~8550 Btu/lb (19.874 MJ/kg) or as tested in accordance with Test Method~~ 8600 Btu/lb (19 990 MJ/kg)~~E711~~

LHV = lower heating value of fuel = ~~7478 Btu/lb (17.382 MJ/kg) or as tested in accordance with Test Method~~ 7988 Btu/lb (18 567 MJ/kg)~~E711~~

ΔT = temperature difference between water entering and exiting the heat exchanger

Q_{out} = total heat output in Btu (MJ)

Q_{in} = total heat input available in test fuel charge in Btu (MJ)

~~*M*~~ *M* = mass flow rate of water lb/min (kg/min)

v_i = volume of water indicated by a totalizing flow meter at the ~~*i*th~~ i^{th} reading in gallons (litres)

v_f = volumetric flow rate of water in heat exchange system in gallons per minute (litres per minute)

t_i ~~= elapsed time from start of test run at~~ = data sampling interval ~~ith reading~~ in minutes

Θ = total length of test run in hours

~~η = delivered~~η_{del} = delivered heating efficiency in percent

η_{SLM} = overall efficiency determined using the CSA B415.1-2010 stack loss method in percent

η_{avg} = weighted average delivered efficiency in percent

F_i = weighting factor for heat output category *i*

~~*T*~~$T1_{avg}$ ~~= average~~ = temperature of water ~~in the load~~ at the inlet on the supply side of the heat ~~exchanger~~exchanger, °F

T2 = temperature of the water at the outlet on the supply side of the heat exchanger, °F

T3 = temperature of water at the inlet to the load side of the heat exchanger, °F

TI_{avg} = average temperature of the appliance and water at start of the test

$$TI_{avg} = (T1 + T2)/2 \text{ at the end of the test, °F} \quad (1)$$

TF_{avg} = average temperature of the appliance and water at the end of the test

TF_{avg} =

$$(T1 + T2)/2 \text{ at the end of the test,°F} \quad (2)$$

MC = fuel moisture content in percent based on dry fuel weight
MC_i = average moisture content of individual fuel pieces on a dry weight basis
MC_{sp} = moisture content of spacers assumed to be 10 %
σ = density of water (lb/gal)
C_p = specific heat of water in Btu per pound °F
C_{steel} = specific heat of steel (0.1 Btu/lb·°F)
W_{fuel} = fuel charge weight in pounds (kilograms)
W_i = weight of individual fuel pieces in pounds (kilograms)
W_{sp} = weight of all spacers used in a fuel load in pounds (kilograms)
W_{app} = weight of empty appliance in pounds
W_{water} = weight of water in supply side of the system in pounds

NOTE 2—After the test is completed, determine the particulate emissions in accordance with Test Method E2515 Eq. 10 ($\boldsymbol{E_T}$).

13.2 *Determine Average Fuel Load Moisture Content:*

$$MC_{Ave} = \frac{[\sum W_i \cdot MC_i]}{\sum W_i} \quad (3)$$

$$MC_{Ave} = \frac{[\sum W_i \cdot MC_i]}{\sum W_i} \quad (3)$$

13.3 *Determine Heat Input:*

$$Q_{in} = (W_{fuel} / (1 + (MC_{ave} / 100))) \times HHV \quad (4)$$

$$Q_{in} = (W_{fuel} / (1 + (MC_{ave} / 100))) \times HHV \quad (5)$$

$$Q_{in\ LHV} = (W_{fuel} / (1 + (MC_{ave} / 100))) \times LHV$$

$$Q_{in\ LHV} = (W_{fuel} / (1 + (MC_{ave} / 100))) \times LHV \quad (5)$$

13.4 *Determine Heat Output and Efficiency:*

13.4.1 Determine heat output as:

$$Q_{out} = \sum[\text{Heat output determined for each sampling time interval}] + \text{Change in heat stored in the appliance} \quad (6)$$

$$Q_{out} = \sum[C_p \times \Delta T \times \text{mass flow rate (lb/min)} \times \text{time interval (min)}] + \text{change in heat stored in the appliance}$$

$$Q_{out} = \left[\sum\left(C_p \cdot \Delta T \cdot \dot{M} \cdot t\right)\right] + (W_{app} \cdot C_{steel} + C_p W_{water}) \cdot (TF_{avg} - TI_{avg}) \quad (7)$$

$$\dot{M} = \text{mass flow rate} = \text{gal/min} \times \text{density of water (lb/gal)} = \text{lb/min}$$

$$\dot{M} = V_f \cdot \sigma$$

$$\sigma = (62.56 + (-0.0003413 \times T_{avg}) + (-0.00006225 \times T_{avg}^2))\ 0.1337 \text{ lb/gal}$$

$$C_p = 1.0014 + (-0.000003485 \times T_{avg}) \text{ Btu/lb °F}$$

$$C_{steel} = 0.1 \text{ Btu/lb °F}$$

$$V_f = (V_i - V_{i-1}) / (t_i - t_{i-1})$$

$$Q_{out} = \left[\sum\left(C_{pi} \cdot \Delta T_i \cdot \dot{M}_i \cdot t_i\right)\right] + (W_{app} \cdot C_{steel} + C_{pa} \cdot W_{water}) \cdot (TF_{avg} - TI_{avg}), \text{ Btu (MJ)} \quad (7)$$

NOTE 2—V_i is the total water volume at the end of interval i and $V_{i\text{-}1}$ is the total water volume at the beginning of the time interval. This calculation is necessary when a totalizing type water meter is used.

where:

i = parameter value for sampling time interval t_i

$$\text{Change in heat stored in the appliance} = [(\text{weight of the appliance} \times 0.1) + (\text{weight of water in the appliance} \times C_p)] \times (\text{final average temperature of the appliance} - \text{initial average temperature of the appliance}) \quad (8)$$

$$M_i = \text{Mass flow rate} = \text{gal/min} \times \text{Density of Water (lb/gal)} = \text{lb/min} \quad (8)$$

$$M_i = V_{f_i} \cdot \sigma_i, \text{ lb/min.} \quad (9)$$

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ASTM E2618-13
https://standards.iteh.ai/catalog/standards/...995404edb7/astm-e2618-13

$$\sigma_i = (62.56 + (-.0003413 \cdot T3_i) + (-.00006225 \cdot T3_i^2)) \cdot 0.1337, \text{ lbs/gal.} \quad (10)$$

$$C_p = 1.0014 + (-.000003485 \cdot T3_i), \text{Btu/lb-°}F \quad (11)$$

$$C_{Steel} = 0.1 \text{ Btu/lb-°F} \quad (12)$$

$$C_{pa} = 1.0014 + (-.000003485 \cdot (TI_{avg} + TF_{avg})/2), \text{Btu/lb-°F} \quad (13)$$

$$V_{f_i} = (V_i - V_{i-1})/(t_i - t_{i-1}), \text{ gal/min.} \quad (14)$$

where:

~~C_p = specific heat of water.~~

V_i = total water volume at the end of interval i
V_{i-1} = total water volume at the beginning of the time interval. This calculation is necessary when a totalizing type water meter is used.

13.4.2 Determine heat output rate as:

~~$$\text{Heat Output Rate} = Q_{out}/\text{test cycle duration in hours} \quad (15)$$~~

$$\text{Heat Output Rate} = Q_{out}/\Theta, \text{ Btu/h (MJ/h)} \quad (15)$$

13.4.3 Determine emission rates and emission factors as:

$$E_{g/MJ} = E_T/(Q_{out} \times 0.001055), \text{ g/MJ} \quad (16)$$

~~$$E_{g/MJ} = E_T/(Q_{out} \times 0.001055)$$~~

~~$$E_{lb/MM\ Btu\ Output} = (E_T/453.59)/(Q_{out} \times 10^{-6}) \quad (17)$$~~

~~$$E_{lb/MM\ Btu\ Input} = (E_T/453.59)/(Q_{in} \times 10^{-6})$$~~

~~$$E_{g/kg} = E_T/(W_{fuel}/(1+MC/100))$$~~

~~$$E_{g/h} = E_T/_{test\ duration}$$~~

$$E_{lbs/MM\ Btu\ output} = (E_T/453.59)/(Q_{out} \times 10^{-6}), \text{ lbs/MMBtu Out} \quad (17)$$

$$E_{g/kg} = E_T/(W_{fuel}/(1+MC/100)), \text{ g/dry kg} \quad (18)$$

$$E_{g/h} = E_T/\Theta, \text{g/h} \quad (19)$$

13.4.4 Determine delivered efficiency as:

$$\eta_{del} = (Q_{out}/Q_{in}) \times 100 \quad (20)$$

~~$$\eta_{del} = (Q_{out}/Q_{in}) \times 100$$~~

~~$$\eta_{del\ LHV} = (Q_{out}/Q_{in\ LHV}) \times 100 \quad (21)$$~~

$$\eta_{del\ LHV} = (Q_{out}/Q_{in\ LHV}) \times 100 \quad (21)$$

13.4.5 Determine η_{SLM} - Overall Efficiency, also known as Stack Loss Efficiency, using Stack Loss Method (SLM). For determination of the average overall thermal efficiency (η_{SLM}) for the test run, use the data collected over the full test run and the calculations in accordance with CSA B415.1-2010, Clause 13.7

13.4.5.1 Whenever the overall efficiency (η_{SLM}) is found to be lower than the delivered efficiency (η_{del}), as determined by Eq 20 of this method, 14.1.7 of the test report must include a discussion of the reasons for this result.

13.5 *Weighted Average Emissions and Efficiency:*

13.5.1 Determine the weighted average emission rate and delivered efficiency from the individual tests in the specified heat output categories. The weighting factors (F_i) are derived from an analysis of American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Bin Data which provides details of normal building heating requirements in terms of percent of design capacity and time in a particular capacity range (or "bin") over the course of a heating season. The values used in this method represent an average of data from several cities located in the northern United States.

~~$$\text{Weighted average delivered efficiency:} \eta_{avg} = \sum \eta_j \times F_j \quad (22)$$~~

~~$$\text{Weighted average emissions:} E_{avg} = \sum E_j \times F_j$$~~

$$\eta_{avg} = \sum \eta_i \cdot F_i, \% \quad (22)$$

$$E_{avg} = \sum E_i \cdot F_i, \text{ lb/mm}BTU_{\text{Output}} \quad (23)$$

13.5.2 ~~*Average Btu/h for 8 h Burn Time*~~ Estimated Average Heat Output ($Q_{out\text{-}8\ h}$) and Efficiency ($\eta_{avg\text{-}8\ h}$) for 8 h burn time (does not apply to particulate fueled appliances):

13.5.2.1 Units tested under this standard typically require infrequent fuelling, 8 to 12 h intervals being typical. Rating unit's based on an Average Output sustainable over an 8 h duration will assist consumers in appropriately sizing units to match the theoretical heat demand of their application.

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ASTM E2618-13
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