Designation: E2779 – 10

Standard Test Method for Determining Particulate Matter Emissions from Pellet Heaters[1]

This standard is issued under the fixed designation E2779; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the fueling and operating protocol for determining particulate matter emissions from fires in pellet or other granular or particulate biomass burning room heaters and fireplace inserts.

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

1.3 *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]

D1102 Test Method for Ash in Wood

D3176 Practice for Ultimate Analysis of Coal and Coke

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

D5373 Test Methods for Instrumental Determination of Carbon, Hydrogen, and Nitrogen in Laboratory Samples of Coal and Coke

E631 Terminology of Building Constructions

E711 Test Method for Gross Calorific Value of Refuse-Derived Fuel by the Bomb Calorimeter (Withdrawn 2011)[3]

E777 Test Method for Carbon and Hydrogen in the Analysis Sample of Refuse-Derived Fuel

E778 Test Methods for Nitrogen in the Analysis Sample of Refuse-Derived Fuel

E871 Test Method for Moisture Analysis of Particulate Wood Fuels

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

2.2 *Other Standards:*

CSA B415.1 (3rd Edition) Performance Testing of Solid-Fuel-Burning Heating Appliances

PFI Standard Specification for Residential/Commercial Densified Fuel

3. Terminology

3.1 *Definitions*—Terms used in this test method are defined in Terminology E631.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *automatically controlled heater, n*—a heater where the burn rate is controlled by a means other than the direct action of adjustment of a burn rate control device by the heater user. This includes heaters with thermostats, proportional controllers or other electronic or mechanical devices that control the heater operation in response to a room or other temperature set point.

3.2.2 *burn pot, n*—the vessel or other defined area within the firebox where fuel and air meet to initiate combustion.

3.2.3 *burn rate, n*—the rate at which test fuel is consumed in the pellet heater during a test run. Measured in kilograms (lb) (dry basis) per hour.

3.2.4 *firebox, n*—the chamber in the pellet heater in which primary combustion of the fuel occurs.

3.2.5 *fuel feed system, n*—mechanism for delivering fuel from the hopper to the burn pot.

3.2.6 *fuel grade, n*—variations in the properties of fuel within any given fuel type. For wood pellets, grading is in accordance with PFI Standard Specification for Residential/Commercial Densified Fuel is an example. For other fuel types, certain physical or chemical properties may be used to differentiate between higher and lower fuel grades.

3.2.7 *fuel hopper, n*—container where fuel is held before being delivered to the burn pot by the fuel feed system.

3.2.8 *fuel type, n*—for a pelletized fuel, the fuel type is defined by the material that was pelletized (for example, "wood

[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] 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.

pellets" or "switch grass pellets"), and for non-pelletized fuel, the fuel type is defined by the material itself (for example, "corn," "walnut hulls" or "cherry pits").

3.2.9 *manually controlled heater, n*—a heater where the burn rate is controlled by the direct action of adjustment of a burn rate control device by the heater user.

3.2.10 *manufacturer's written instructions, n*—specific information regarding the fueling and operation procedures recommended by the heater manufacturer and included with the heater. These instructions must be consistent with information provided to the heater end-user in the owner's manual or equivalent.

3.2.11 *owner's manual, n*—written information provided to the heater end-user regarding the installation and recommended fueling and operating procedures that will help the heater user to achieve the best heater performance. It is also referred as the installation and operation guide or other equivalent title.

3.2.12 *particulate matter (PM), n*—all gas-borne matter resulting from combustion of solid fuel, as specified in this test method, which is collected in accordance with Test Method E2515.

3.2.13 *pellet burning heater, n*—a heater specifically designed to burn pellet, granular or particulate fuels only, and which includes a fuel hopper and fuel feed system as integral parts.

3.2.14 *pellet heater venting, n*—venting system or components specified for use with the pellet heater by the pellet heater manufacturer.

3.2.15 *test facility, n*—the area in which the pellet heater is installed, operated, and sampled for emissions.

3.2.16 *test fuel, n*—for any fuel type recommended by the manufacturer in the manufacturer's written instructions or the owner's manual for use in the pellet heater, the test fuel when more than one fuel grade is recommended is the lowest recommended grade of that fuel type.

3.2.17 *test fuel weight, n*—the mass of fuel burned in the pellet heater during the test run or test run segment.

3.2.18 *test run, n*—an integrated emission test cycle including test run segments ranging from minimum to maximum burn rates.

3.2.19 *test run segments, n*—individual portions of the test run conducted at the minimum, medium and maximum burn rates achievable by the pellet heater.

3.2.20 *wood heater, n*—an enclosed, wood burning appliance capable of and intended for space heating and/or domestic water heating.

4. Summary of Test Method

4.1 This test method is used in conjunction with Test Method E2515. The pellet heater under evaluation is fueled with the fuel type or types specified by the pellet heater manufacturer. The fuel types may be any pelletized, granular or particulate biomass fuel for which the pellet heater has been designed to combust. The fuels must be able to be fed to the pellet heater burn pot from a fuel storage hopper using an auger or other fuel feeding mechanism. An integrated test run is conducted including three burn rate segments ranging from low to maximum. The length of time of each burn rate segment determines the weighting given to each segment in the integrated test result. The weight of the fuel is measured as the change in weight of the heater from the beginning to end of each burn rate segment of the test run. Burn rate for each test run segment is determined based on the weight of the fuel consumed during the segment divided by the length of the segment and corrected to a dry fuel basis. Particulate sampling begins after the heater has been in operation at the burn rate setting for the first test run segment for at least one hour and the test run is terminated after the integrated test run cycle is complete. The total particulate emissions are determined over the full integrated test run length. The average particulate emissions rate is then determined from the total particulate emissions determined using Test Method E2515 divided by the length of the integrated test run and is reported in grams of particulate per hour. The average particulate emission factor may also be determined from the total particulate emissions divided by the total dry basis weight of the fuel consumed during the integrated test run and is reported in grams of particulate per dry kilogram of fuel. If the efficiency of the heater is measured, average particulate emissions may also be reported in grams of particulate per unit of average heat delivered over the integrated test run. A separate test run is required for each fuel type specified by the manufacturer for use with the heater. If more than one grade of a given fuel type is recommended by the manufacturer in the manufacturer's written instructions for use in the heater, the test fuel shall be the lowest recommended grade.

5. Significance and Use

5.1 This test method is used for determining average emission rates and average emission factors for pellet heaters.

5.1.1 The emission factor is useful for determining emission performance during product development.

5.1.2 The emission factor is useful for the air quality regulatory community for determining compliance with emission performance limits.

5.1.3 The emission rate may be useful for the air quality regulatory community for determining impacts on air quality from pellet heaters.

5.2 The reporting units are grams of particulate per hour and grams of particulate per kilogram of dry fuel.

5.2.1 Appropriate reporting units for comparing emissions from all types of solid fuel fired appliances: g/kg.

5.2.2 Appropriate reporting units for predicting atmospheric emission impacts: g/h or g/MJ.

6. Safety

6.1 *Disclaimer*—This test method may involve hazardous materials, operations, and equipment. This test method may not address all of the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to performing this test method.

7. Equipment and Supplies

7.1 *Platform Scale*—A scale capable of weighing the test pellet heater and attached venting, including the weight of the test fuel, to within 0.05 kg (0.1 lb). Must meet the calibration requirements specified in 8.1.

7.2 *Pellet Heater Flue Gas Temperature Measurement Device*—A 3.2 mm (0.125 in.) diameter sheathed, non-isolated junction Type K thermocouple capable of measuring flue gas temperature with an accuracy of 2.2°C (4.0°F) or 0.75 % of the reading, which ever is greater. Must meet calibration requirements specified in 8.2.

8. Calibration and Standardization

8.1 *Platform Scale*—Perform a multipoint calibration (at least five points spanning the operational range) of the platform scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test, audit the scale with the test fireplace in place by weighing at least one calibration weight (ASTM Class F) that corresponds to between 20 and 80 % of the expected test fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.05 kg (0.1 lb) or 1 % of the expected test fuel charge weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

8.2 *Temperature Sensors*—Temperature measuring equipment shall be calibrated before initial use and at least semi-annually thereafter. Calibrations shall be in compliance with National Institute of Standards and Technology (NIST) Monograph 175–Standard Limits of Error.

9. Procedure

9.1 *Pre-conditioning of the Pellet Heater*—The pellet heater must be pre-conditioned before a test series begins.

9.1.1 Set up the pellet heater in accordance with written instructions provided by the manufacturer. The total vent height measured from the floor or top of the platform scale shall be 4.6 ± 0.3 m (15 ± 1 ft) unless otherwise specified in the manufacturer's written instructions. The venting type used shall be in accordance manufacturer's written instructions.

9.1.2 Install a flue-gas temperature measurement device at the center of the flue, 2.6 ± 0.15 m (8.5 ± 0.5 ft) above the floor or top of the platform scale.

9.1.3 Operate the pellet heater for at least 48 hours at a medium burn rate as defined in 9.5.1 using any fuel specified by the manufacturer for use in the appliance. The hours of operation do not need to be continuous. Additional pre-conditioning is not required when additional fuel types are tested in the same test series.

9.1.4 Record the time and weight for all fuel added.

9.1.5 Record the flue-gas temperature at least once during each hour of operation.

9.1.6 Allow the pellet heater to cool to room temperature and remove all ash, or other debris from the firebox.

9.1.7 Clean the venting system using a standard chimney brush appropriately sized for the chimney.

9.2 Install the pellet heater in the test facility.

9.2.1 Set up the pellet heater in accordance with instructions provided by the manufacturer. Place the pellet heater centrally on the platform scale. The total vent height measured from the top of the platform scale shall be 4.6 ± 0.3 m (15 ± 1 ft) unless otherwise specified in the manufacturer's written instructions. The venting type used shall be in accordance manufacturer's written instructions.

NOTE 1—The venting that is used for testing should be documented in the test data and test report.

9.2.2 Center the vent outlet under the dilution tunnel hood. Refer to Test Method E2515 for specific requirements including positioning the flue outlet to meet induced draft and smoke capture requirements.

9.2.3 Install a flue-gas temperature measurement device at the center of the vent, 2.6 ± 0.15 m (8.5 ± 0.5 ft) above the top of the platform scale.

9.3 *Fuel:*

9.3.1 *Fuel Properties*—A representative sample of the fuel used for any test run, shall be analyzed for Higher Heating Value in accordance with Test Method E711. Moisture content shall be determined in accordance with Test Methods D4442 or Test Method E871.

9.3.1.1 If determining optional thermal efficiency and heat output in accordance with 9.5.1 and Annex A1, a representative sample of the fuel used for any test run shall be analyzed for ash in accordance with Test Method D1102 and carbon, hydrogen, nitrogen and oxygen (ultimate analysis) in accordance with Test Methods E777 and E778, or Practice D3176 and Test Methods D5373.

9.3.2 *Fuel Temperature*—The test fuel temperature shall be within the allowable test facility temperature range as in accordance with Test Method E2515. The fuel temperature may be determined by measuring the temperature of the room where the test fuel has been stored for at least 24 hours immediately prior to use in a test run.

9.4 *Test Run Requirements:*

9.4.1 *Integrated Test Run*—A single test run comprised of minimum, medium and maximum burn rate segments shall be conducted. The burn rate requirements for each segment, except as allowed in 9.4.1.4 or 9.4.1.5, as well as the length of time for each segment are specified in Table 1.

9.4.1.1 *Maximum Burn Rate*—For the maximum burn rate category, the pellet heater shall be operated with the control or controls set at the position(s) as specified by the manufacturer's written instructions to achieve the highest achievable burn rate.

9.4.1.2 *Medium Burn Rate Category*—For burn rates in the medium segment, except as allowed in 9.4.1.4 or 9.4.1.5, the pellet heater shall be operated with the control or controls set in the position(s) as needed to achieve a burn rate that is ≤50 % of the maximum burn rate.

TABLE 1

Burn Rate Segment	Maximum	Medium	Minimum
Description	Maximum achievable	≤ 50% of Maximum	Minimum achievable
Time at Burn Rate	60 +5 / – 0 minutes	120 +5 / – 0 minutes	180 +5 / – 0 minutes

9.4.1.3 *Minimum Burn Rate Segment*—For burn rates in the minimum burn rate segment, except as allowed in 9.4.1.4 or 9.4.1.5, the pellet heater shall be operated with the control or controls set at the position(s) as specified in the manufacturer's written instructions to achieve the lowest continuously firing burn rate or a burn rate ≤ 0.50 dry kg/h, which ever is greater.

9.4.1.4 For automatically controlled heaters that operate at single burn rates and that achieve the desired heat output to the home by cycling on and off in reaction to the heat demand in accordance with a room thermostat or other automatic control device, the burn rate categories during testing shall be achieved by artificial manipulation of the controls. The high burn rate segment is 60 minutes-on. For the medium category segment the heater shall be operated for two cycles of 30 minutes-on and 30 minutes-off. For the low category segment, the heater shall be operated for three cycles of 20 minutes-on and 40 minutes-off.

9.4.1.5 For manually controlled heaters that have two or more fixed burn rate control settings, the integrated test cycle shall be as in accordance with Table 1 except:

(1) For manually controlled heaters with two burn rate control settings (that is, High and Low): 300 +5 / – 0 minutes at the Low burn rate setting, 60 +5 / – 0 minutes at the High setting.

(2) For manually controlled heaters with three burn rate control settings (that is, High, Medium, Low), the burn rate segments shall be as in accordance with Table 1 except that the burn rate for the medium segment shall be as tested at the medium burn rate control setting.

(3) For manually controlled heaters with four or more burn rate control settings, the burn rate segments shall be as in accordance with Table 1 except the control setting to be used for the medium burn rate test segment shall be the setting that provides a burn rate closest to the requirements in accordance with Table 1.

9.4.2 *Pre-burn Ignition*—Ignite a fire in the pellet heater in accordance with the manufacturer's written instructions and adjust the heater controls to achieve the desired burn rate for the high burn rate test run segment. Operate the heater at the high burn rate for at least 1 hour before the start of the integrated test run.

9.4.3 *Test Run Start:*

9.4.3.1 When the pellet heater has operated for at least 1 hour at the high burn rate for the first test run segment, add the amount of test fuel to the supply hopper as necessary to complete the full integrated test run, record the weight of the test fuel in the supply hopper (the pellet heater weight), and start the test run. Add no additional test fuel to the hopper during the test run.

9.4.3.2 Record the pellet heater flue gas temperature, the initial sampling method measurement values, the time at the start of the test, and begin the emission sampling in accordance with the requirements of Test Method E2515.

9.4.3.3 After the pellet heater has operated for the required time for the high burn test run segment in accordance with 9.4.1 and Table 1, adjust the pellet heater control(s) as required to meet allowable burn rate range in accordance with 9.4.1 and Table 1 for the medium burn rate test run segment.

9.4.3.4 After the pellet heater has operated for the required time for the medium burn rate test run segment in accordance with 9.4.1 and Table 1, adjust the pellet heater control(s) as required to meet allowable burn rate range in accordance with 9.4.1 and Table 1 for the low burn rate test run segment.

9.4.3.5 The test run segments must be run in order from high to low.

9.4.4 *Data Recording*—Record the test fuel weight data, pellet heater flue gas temperature and operational data, and emission sampling data as described in Test Method E2515 at intervals no greater than 10 minutes.

9.4.4.1 Record the run time and test fuel weight at the end of the high and medium test run segments.

9.4.5 *Test Run Completion*—Continue emission sampling over the full length of the integrated test run. At the end of the test run, stop the particulate sampling in accordance with Test Method E2515, and record the final test fuel weight, the total run time, and all final measurement values, including the pellet heater flue gas temperature.

9.4.6 *Calculations*—Determine the average test run segment burn rate using the difference between the starting weight of test fuel and the ending weight of the test fuel in the fuel hopper at completion for each test run segment and the procedures described in 10.2. Complete the other calculations as described in Section 10.

9.4.7 *Auxiliary Pellet Heater Equipment Operation:*

9.4.7.1 Heat exchange blowers sold with the pellet heater shall be operated during the test run following the manufacturer's written instructions. In the absence of manufacturer's written instructions, operate the heat exchange blower set at the highest air flow setting. (Automatically operated blowers shall be operated as designed.) Record all adjustments on a pellet heater operational written record.

9.4.7.2 If the pellet heater is sold with a heat exchange blower as an option, a separate integrated test run in accordance with 9.4.1 is required with and without the blower installed for the first fuel type tested. For the test run with the blower installed, operate the blower in accordance with the requirements of 9.4.7.

9.4.7.3 For subsequent test runs with other fuel types, test only with the blower condition in accordance with 9.4.7.2 that resulted in the highest particulate emissions.

9.4.8 *Additional Test Runs*—The testing laboratory may conduct more than one integrated test run. If more than one integrated test run is conducted, the results from at least two thirds of the test runs conducted shall be arithmetically averaged to determine the reported average emission rate (see 10.2). The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the reported average emission rate.

9.4.9 *Alternative Fuels*—When alternative fuels are recommended by the manufacturer for use in the pellet heater in the manufacturer's written instructions, conduct a full integrated test run for each of the recommended alternative fuels in accordance with 9.3 and 9.4. Use the appliance control settings recommended in the manufacturer's written instructions for the fuel type being tested. Report the test results for each fuel tested.

9.5 *Optional Thermal Efficiency and Heat Output Determination:*

9.5.1 Refer to Annex A1 for the procedures used to determine the overall thermal efficiency and heat output for the full integrated test run or for any or all of the individual burn rate segments of the full test run.

10. Data Analysis and Calculations

10.1 Carry out calculations, retaining at least one extra significant figure beyond that of the acquired data. Round off figures after the final calculation. Other forms of the equations may be used as long as they give equivalent results.

10.2 *Nomenclature:*

$$M_{Bdb} = (M_{Swb} - M_{Ewb})\,(100/(100+FM)) \quad (1)$$

where:

FM = average fuel moisture of test fuel, % dry basis,
M_{Swb} = weight of test fuel in hopper at start of test run, wet basis, kg (lb),
M_{Ewb} = weight of test fuel in hopper at end of test run, wet basis, kg (lb), and
M_{Bdb} = weight of test fuel burned during test run, dry basis, kg (lb).

$$M_{BSidb} = (M_{SSiwb} - M_{ESiwb})\,(100/(100+FM)) \quad (2)$$

where:

M_{SSiwb} = weight of test fuel in hopper at start of test run segment i, wet basis, kg (lb),
M_{ESiwb} = weight of test fuel in hopper at end of test run segment i, wet basis, kg (lb),
M_{BSidb} = weight of test fuel burned during test run segment i, dry basis, kg (lb), and
i = test run segments in accordance with 9.4, Table 1.

$$BR = \frac{60\,M_{Bdb}}{\theta} \quad (3)$$

where:

BR = average dry burn rate over the full integrated test run, kg/h (lb/h), and
θ = total length of full integrated test run, min.

$$BR_{Si} = \frac{60\,M_{BSidb}}{\theta_{Si}} \quad (4)$$

where:

BR_{Si} = average dry burn rate over test run segment i, kg/h (lb/h), and
θ_{Si} = total length of test run segment i, min.

$$PM_R = 60(E_T/\theta) \quad (5)$$

where:

E_T = total particulate emissions for full integrated test run measured using Test Method E2515, g (lb),
θ = total length of test run, min, and
PM_R = average particulate emission rate over the full integrated test run, g/h.

$$PM_F = E_T/M_{Bdb} \quad (6)$$

where:

PM_F = average particulate emission factor over the full integrated test run, g/dry kg of fuel burned.

$$PM_H = E_T/E_O \quad (7)$$

where:

E_O = average measured overall heat output over the full integrated test run from Annex A1, MJ (MMBTU), and
PM_H = average particulate emissions in accordance with unit of average heat output over the full integrated test run, g/MJ (lb/MMBtu).

11. Precision and Bias

11.1 *Precision*—It is not possible to specify the precision of the procedure in this test method for measuring pellet heater emissions because the appliance operation and fueling protocols and the appliances themselves produce variable amounts of emissions and, therefore, the results cannot be used to determine reproducibility or repeatability of this measurement method.

11.2 *Bias*—No information can be presented on the bias of the procedure in this test method for measuring pellet heater emissions because no material having an accepted reference value is available.

12. Keywords

12.1 biomass fuel; emissions; granular fuel; particulate; particulate fuel; particulate matter; pellet heater; pellet stove

ANNEX

(Mandatory Information)

A1. PELLET HEATER THERMAL EFFICIENCY AND HEAT OUTPUT DETERMINATION

A1.1 Scope

A1.1.1 This annex to the test method covers the determination of overall efficiency and heat output for pellet and other automatically fed biomass heaters.

A1.2 Referenced Documents

A1.2.1 *ASTM Standards:*

D1102 Test Method for Ash in Wood

D3176 Practice for Ultimate Analysis of Coal and Coke

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

D5373 Test Methods for Instrumental Determination of Carbon, Hydrogen, and Nitrogen in Laboratory Samples of Coal

E711 Test Method for Gross Calorific Value of Refuse-Derived Fuel by the Bomb Calorimeter

E777 Test Method for Carbon and Hydrogen in the Analysis Sample of Refuse-Derived Fuel

E778 Test Methods for Nitrogen in the Analysis Sample of Refuse-Derived Fuel

E871 Test Method for Moisture Analysis of Particulate Wood Fuels

A1.2.2 *Other Standards:*

CSA B415.1 (3rd Edition) Performance Testing of Solid-Fuel-Burning Heating Appliances

A1.3 Summary of Test Method

A1.3.1 The procedures in this annex may be used in conjunction with the test method to allow determination of the overall thermal efficiency and the heat output for each burn rate segment of the integrated test run in accordance with 9.4.1 as well as the integrated average overall thermal efficiency and integrated average heat output over the full test run. Additionally, in conjunction with the test method, the results determined by the procedures in the annex may be used to determine the integrated average particulate emissions in accordance with delivered heat output over the full test run, expressed in g/MJ (lb/MMBTU).

A1.4 Significance and Use

A1.4.1 This annex is used for determining the integrated average thermal efficiency and heat output for pellet heaters.

A1.4.2 This annex is used for determining the average thermal efficiency and heat output for each burn rate segment of the integrated test run.

A1.4.3 This annex is used to determine the particulate emission rate per unit of heat delivered. This is useful when comparing different types of heating equipment.

A1.5 Procedure

A1.5.1 The procedures used in the annex shall be in accordance with Clauses 6.1.3, 6.2.1, 6.2.2, 6.3, 6.7.2, 6.7.4, 10.4.3 (a), 10.4.3 (f-j), and 13.7 of CSA B415.1, 3rd Edition, 2010.

A1.5.1.1 Determine the test fuel ash content in accordance with Test Method D1102 and the carbon, hydrogen, nitrogen and oxygen content (ultimate analysis) in accordance with Test Methods E777 and E778.

A1.5.1.2 Measure and record the test room air temperature in accordance with the requirements of CSA B415.1, Clauses 6.2.1 and 10.4.3 (g).

A1.5.1.3 Measure and record the flue gas temperature in accordance with the requirements of CSA B415.1, Clauses 6.2.2 and 10.4.3 (f).

A1.5.1.4 Determine and record the Carbon Monoxide (CO) and Carbon Dioxide (CO_2) concentrations in the flue gas in accordance with CSA B415.1, Clauses 6.3 and 10.4.3 (i) and (j).

A1.5.1.5 Measure and record the test fuel weight in accordance with the requirements of CSA B415.1, Clause 10.4.3 (h).

A1.5.1.6 Record the test run time in accordance with the requirements of CSA B415.1, Clause 10.4.3 (a).

A1.6 Data Analysis and Calculations

A1.6.1 *Thermal Efficiency and Heat Output:*

A1.6.1.1 For determination of the average thermal efficiency and average heat output over the full integrated test run used the data collected over the full test run and the calculations in accordance with CSA B415.1, Clause 13.7.

A1.6.1.2 For determination of the average thermal efficiency and average heat output for each of the individual burn rate segments of the test run, separate the data collected by burn rate segment and use the calculation procedures in CSA B415.1, Clause 13.7 for each data subset.

A1.6.2 *Nomenclature:*

E_O = average measured overall heat output over the full integrated test run, MJ (MMBTU),

E_{Oi} = average measured overall heat output for burn rate segment i, MJ (MMBTU),

i = high, medium or low burn rate segment,

η_r = overall efficiency for full integrated test run, %, and

η_{ri} = overall efficiency for burn rate segment, i.