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ALTERNATE HEATING SYSTEMS
TEST REPORT

SCOPE OF WORK
EPA EMISSIONS TESTING FOR MODEL SE210 SOLID FUEL HYDRONIC HEATER

REPORT NUMBER
104711998MID-007R2

TEST DATE(S)
09/21/21 - 09/24/21

ISSUE DATE **[REVISED DATE]**
09/29/21 03/09/22

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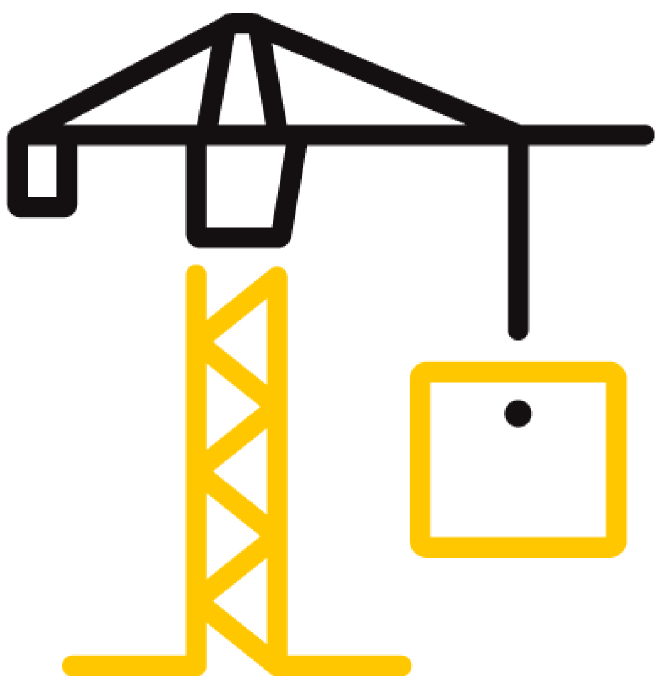

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TEST REPORT FOR ALTERNATE HEATING SYSTEMS
Report No.: 104711998MID-007R2
Date: 3/9/22

REPORT ISSUED TO

ALTERNATE HEATING SYSTEMS
2393 Little Egypt Road
Harrisonville, PA 17228

SECTION 1
SCOPE

Intertek Building & Construction (B&C) was contracted by Alternate Heating Systems to perform testing in accordance with EPA 40 CFR Part 60 "Standards of Performance for New Residential Wood Heaters, New Residential Hydronic Heaters and Forced-Air Furnaces", ASTM E2515-2017 Standard Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel, ASTM E2618-2013 (R2019) Measurement of Particulate Emissions and Heating Efficiency of Wood-Fired Hydronic Heating Appliances, and CSA B415.1-10 (R2020) Performance Testing of Solid-Fuel-Burning Heating Appliances on their model SE210 Solid Fuel Hydronic Heater. Results obtained are tested values and were secured by using the designated test method(s). Testing was conducted at Intertek test facility in Middleton, WI.

This report does not constitute certification of this product nor an opinion or endorsement by this laboratory.

SECTION 2
SUMMARY OF TEST RESULTS

The appliance tests resulted in the following performance:

Particulate Emissions: 0.15 lb./MMBtu – Output (Cat 1)
Particulate Emissions: 0.14 lb./MMBtu – Output (Cat 2)
Particulate Emissions: 0.11 lb./MMBtu – Output (Cat 3)
Particulate Emissions: 0.07 lb./MMBtu – Output (Cat 4)
Carbon Monoxide Emissions: 4.49 g/min
Heating Efficiency: 70.9% (Higher Heating Value Basis)
Heating Efficiency: 66.6% (Higher Heating Value Basis – CSA B415.1 Stack Loss)

For INTERTEK B&C:

COMPLETED BY:	Ken Slater	**REVIEWED BY:**	Brian Ziegler
TITLE:	Associate Engineer - Hearth	**TITLE:**	Technical Team Leader - Hearth
SIGNATURE:	Ken Slater	**SIGNATURE:**	
DATE:	03/09/22	**DATE:**	03/09/22

aaa:bbb

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SECTION 3
TEST METHOD(S)

The specimen was evaluated in accordance with the following:

EPA 40 CFR Part 60-2015 - Standards of Performance for New Residential Wood Heaters, New Residential Hydronic Heaters and Forced-Air Furnaces

ASTM E2515-2017 - Standard Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel

ASTM E2618-2013 (R2019) - Standard Test Method for Measurement of Particulate Emissions and Heating Efficiency of Wood-Fired Hydronic Heating Appliances

CSA B415.1-2010 (R2020) - Performance Testing of Solid-Fuel-Burning Heating Appliances

SECTION 4
MATERIAL SOURCE

A sample was submitted to Intertek directly from the client. The sample was not independently selected for testing. The test unit was received at Intertek in Middleton, WI on September 20, 2021 and was shipped via the client. The unit was inspected upon receipt and found to be in good condition. The unit was set up following the manufacturer's instructions without difficulty.

Following assembly, the unit was placed on the test stand. Prior to beginning the emissions tests, the manufacturer operated the unit for a minimum of 50 hours at high-to-medium burn rates to break in the heater. This break-in period was performed by the Alternate Heating System’s staff and datasheets are included in the final report. The unit was found to be operating satisfactory during this break-in. The 50 plus hours of pre-burning were conducted from July 27, 2020 to September 16, 2021. The fuel used for the break-in process was cordwood.

The unit's chimney system and laboratory dilution tunnels were cleaned using standard wire brush chimney cleaning equipment. On September 20, 2021 the unit was set-up for testing.

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SECTION 5
EQUIPMENT

Equipment	INV Number	Calibration Due	MU
Timer	1212	4/5/2022	0.7 sec
Timer	646	4/5/2022	0.7 sec
Pressure Transducer	1406	1/13/2022	.0007 inH2O
Data Acquisition	986	10/16/2021	0.06 Deg F
Scale	1539	10/1/2021	1.18 lbs
Hygrometer	1450	11/23/2021	0.35 RH
Flow Meter	1413	2/20/2022	0.020 lpm
Flow Meter	1414	2/20/2022	0.020 lpm
Flow Meter	1519	2/20/2022	0.020 lpm
Balance	713	10/6/2021	0.00044 g
Wood Scale	8	10/6/2021	0.081 lbs
Dry Gas Meter	13	8/12/2022	0.003 cf
Moisture Block	1393	10/5/2021	0.006/0.0007 Mohm
Moisture Block	1380	10/5/2021	0.007/0.0007 Mohm
Anemometer	1457	5/14/2022	4 fpm

SECTION 6
LIST OF OFFICIAL OBSERVERS

NAME	COMPANY
Caleb Gingerich	Alternate Heating Systems
Ken Slater	Intertek B&C
Brian Ziegler	Intertek B&C
Justin Buck	Intertek B&C

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SECTION 7
TEST PROCEDURE

From September 21, 2021 to September 24, 2021, the unit was tested for EPA emissions. For hydronic heaters, the test was conducted in accordance with ASTM E2618. The fuel used for the test run was oak cordwood.

The applicable EPA regulatory limits are:

Step 2 – 2020 – 0.10 lb./MMBtu Output - Cribs.

Step2 – 2020 – 0.15 lb./MMBtu Output – Cordwood.

TEST SET-UP DESCRIPTON

A 6” diameter insulated chimney system was connected to the right rear side of the unit with a tee. The chimney was then installed to 15’ above floor level.

AIR SUPPLY SYSTEM

Combustion air enters an inlet located at the rear of the heater, which is directed to the firebox and combustion chamber. All gases exit through the 6” flue also located at the top rear side of the heater. The exhaust gases are assisted by a combustion blower.

TEST FUEL PROPERTIES

Oak cordwood was used. The Oak has a measured heating value of 8600 Btu/hr and a moisture content ranging from 18% to 28% on a dry basis.

SAMPLING LOCATIONS

Particulate samples are collected from the dilution tunnel at a point 20 feet from the tunnel entrance. The tunnel has two elbows and two mixing baffles in the system ahead of the sampling section. (See Figure 3.) The sampling section is a continuous 13 foot section of 6 inch diameter pipe straight over its entire length. Tunnel velocity pressure is determined by a standard Pitot tube located 60 inches from the beginning of the sampling section. The dry bulb thermocouple is located six inches downstream from the Pitot tube. Tunnel samplers are located 60 inches downstream of the Pitot tube and 36 inches upstream from the end of this section. (See Figure 1.)

Stack gas samples are collected from the steel chimney section 8 feet ± 6 inches above the scale platform. (See Figure 2.)

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FIGURE 1 – DILUTION TUNNEL

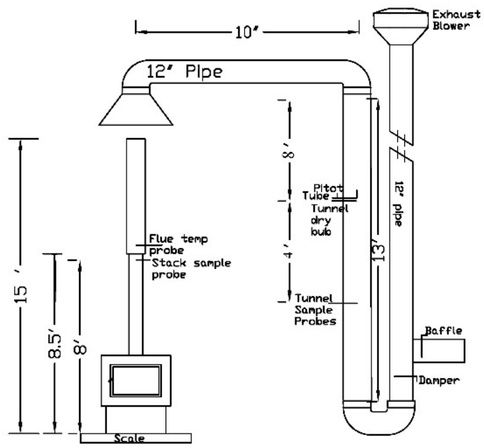
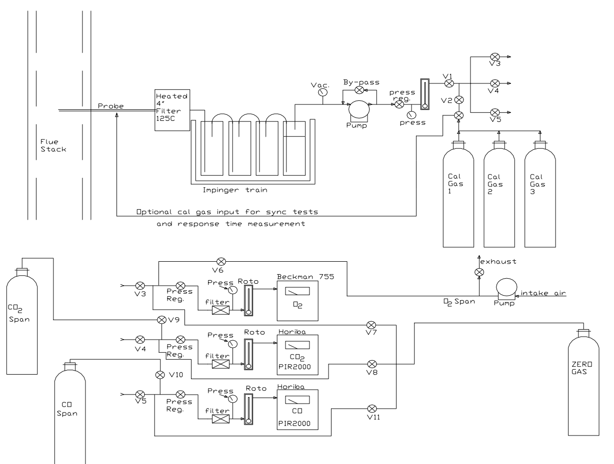


FIGURE 1

FIGURE 2 – STACK GAS SAMPLE TRAIN



ITS FLUE GAS SAMPLE TRAIN

FIGURE 2

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FIGURE 3 – DILUTION TUNNEL SAMPLE SYSTEMS

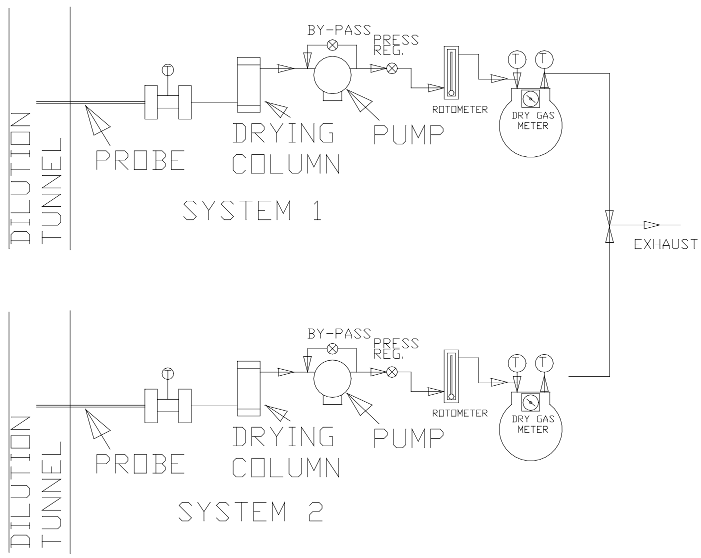

Figure 3

SAMPLING METHODS

PARTICULATE SAMPLING

Particulates were sampled in strict accordance with ASTM E2515-2017. This method uses two identical sampling systems with Gelman A/E 61631 binder free, 47-mm diameter filters. The dryers used in the sample systems are filled with “Drierite” before each test run. In order to measure first-hour emissions rates a third filter set is prepared. At one hour into the test run, the third filter was turned off. The third filter set was analyzed individually to determine the first hour and total emissions rate.

INSTRUMENT CALIBRATION

DRY GAS METERS

At the conclusion of each test program the dry gas meters are checked against our standard dry gas meter. Three runs are made on each dry gas meter used during the test program. The average calibration factors obtained are then compared with the six-month calibration factor and, if within 5%, the six-month factor is used to calculate standard volumes. Results of this calibration are contained in Appendix D.

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An integral part of the post-test calibration procedure is a leak check of the pressure side by plugging the system exhaust and pressurizing the system to 10" W.C. The system is judged to be leak free if it retains the pressure for at least 10 minutes.

The standard dry gas meter is calibrated every 6 months using a Spirometer designed by the EPA Emissions Measurement Branch. The process involves sampling the train operation for 1 cubic foot of volume. With readings made to .001 ft^3, the resolution is .1%, giving an accuracy higher than the ±2% required by the standard.

STACK SAMPLE ROTAMETER

The stack sample rotometer is checked by running three tests at each flow rate used during the test program. The flow rate is checked by running the rotometer in series with one of the dry gas meters for 10 minutes with the rotometer at a constant setting. The dry gas meter volume measured is then corrected to standard temperature and pressure conditions. The flow rate determined is then used to calculate actual sampled volumes.

GAS ANALYZERS

The continuous analyzers are zeroed and spanned before each test with appropriate gases. A mid-scale multi-component calibration gas is then analyzed (values are recorded). At the conclusion of a test, the instruments are checked again with zero, span and calibration gases (values are recorded only). The drift in each meter is then calculated and must not exceed 5% of the scale used for the test.

At the conclusion of each unit test program, a three-point calibration check is made. This calibration check must meet accuracy requirements of the applicable standards. Consistent deviations between analyzer readings and calibration gas concentrations are used to correct data before computer processing. Data is also corrected for interferences as prescribed by the instrument manufacturer's instructions.

TEST METHOD PROCEDURES

LEAK CHECK PROCEDURES

Before and after each test, each sample train is tested for leaks. Leakage rates are measured and must not exceed 0.02 CFM or 4% of the sampling rate. Leak checks are performed checking the entire sampling train, not just the dry gas meters. Pre-test and post-test leak checks are conducted with a vacuum of 10 inches of mercury. Vacuum is monitored during each test and the highest vacuum reached is then used for the post-test vacuum value. If leakage limits are not met, the test run is rejected. During, these tests the vacuum was typically less than 2 inches

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of mercury. Thus, leakage rates reported are expected to be much higher than actual leakage during the tests.

TUNNEL VELOCITY/FLOW MEASUREMENT

The tunnel velocity is calculated from a center point Pitot tube signal multiplied by an adjustment factor. This factor is determined by a traverse of the tunnel as prescribed in EPA Method 1. Final tunnel velocities and flow rates are calculated from EPA Method 2, Equation 6.9 and 6.10. (Tunnel cross sectional area is the average from both lines of traverse.)

Pitot tubes are cleaned before each test and leak checks are conducted after each test.

PM SAMPLING PROPORTIONALITY

Proportionality was calculated in accordance with ASTM E2515-17. The data and results are included in Appendix C.

DEVIATIONS FROM STANDARD METHOD:

None

SECTION 8
TEST CALCULATIONS

AVERAGE TEMPERATURE OF THE APPLIANCE AND WATER AT THE START OF THE TEST – EPA METHOD 28 WHH:

$$TI_{avg} = (T1 + T2)/2$$

where:
T1 = Temperature of water at the inlet on the supply side of the heat exchanger
T2 = Temperature of water at the outlet on the supply side of the heat exchanger

AVERAGE TEMPERATURE OF THE APPLIANCE AND WATER AT THE END OF THE TEST – EPA METHOD 28WHH

$$TF_{avg} = (T1+T2)/2$$

where:
T1 = Temperature of water at the inlet on the supply side of the heat exchanger
T2 = Temperature of water at the outlet on the supply side of the heat exchanger

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AVERAGE FUEL LOAD MOISTURE CONTENT – EPA METHOD 28WHH

$$MC_{avg} = [\sum W_i \times MC_i] / \sum W_i$$

where:

MC = Fuel Moisture content in percent dry basis
MC_i = Average moisture content f individual fuel pieces on a dry weight basis
W_i = Weight of individual fuel pieces in pounds (kilograms)

HEAT INPUT – EPA METHOD 28WHH

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

where:

Q_{in} = total heat input available in test fuel charge in Btu (MJ)
W_{fuel} = fuel charge weight in pounds (kilograms)
MC_{avg} = average fuel moisture content in percent based on dry fuel weight
HHV = higher heating value of fuel = 8600 Btu/lb (19 990 MJ/kg)

HEAT OUTPUT AND EFFICIENCY – EPA METHOD 28WHH

$$Q_{out} = [\sum(C_{pi} \times \Delta T_i \times M_i \times t_i)] + (W_{app} \times C_{steel} + C_{pa} \times W_{water}) \times (TF_{avg} - TI_{avg}), \text{ Btu (MJ)}$$

where:

Q_{out} = ∑[Heat output determined for each sampling time interval] + Change in heat stored in the appliance
$_i$ = parameter value for sampling time interval ti
t_i = data sampling interval in minutes
M = mass flow rate of water lb/min (kg/min)
ΔT = temperature difference between water entering and exiting the heat exchanger
C_p = specific heat of water in Btu per pound °F
W_{app} = weight of empty appliance in pounds
C_{steel} = specific heat of steel (0.1 Btu/lb·°F)
C_{pa} = $1.0014 + (-0.000003485 \times (TI_{avg} + TF_{avg}) / 2)$, Btu/lb-°F
W_{water} = weight of water in supply side of the system in pounds
TF_{avg} = average temperature of the appliance and water at the end of the test
TI_{avg} = average temperature of the appliance and water at start of the test

HEAT OUTPUT RATE – EPA METHOD 28WHH

$$\text{Heat Output Rate} = Q_{out} / \Theta, \text{ Btu/hr. (MJ/hr.)}$$

where:

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Q_{out} = total heat output in Btu (MJ)
Θ = total length of test run in hours

EMISSIONS RATES AND EMISSIONS FACTORS – EPA METHOD 28WHH

$E_{g/MJ} = E_T/(Q_{out} \times 0.001055)$, g/MJ
$E_{lbs/MM\ Btu\ output} = (E_T/453.59)/(Q_{out} \times 1000000)$, lbs/MMBtu Out
$E_{g/kg} = E_T/(W_{fuel}/(1 + MC/100))$, g/dry kg
$E_{g/h} = E_T/\Theta$, g/h

where:
$E_{g/MJ}$ = emission rate in grams per mega joule of heat output
$E_{lb/MMBtu\ Output}$ = emissions rate in pounds per million Btu of heat output
$E_{g/kg}$ = emissions factor in grams per kilogram of dry fuel burned
$E_{g/h}$ = emission rate in grams per hour
E_T = total particulate emissions measured during a full test cycle, grams
Q_{out} = total heat output in Btu (MJ)
W_{fuel} = fuel charge weight in pounds (kilograms)
Θ = total length of test run in hours

DELIVERED EFFICIENCY – EPA METHOD 28WHH

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

where:
η_{del} = delivered heating efficiency in percent
Q_{out} = total heat output in Btu (MJ)
Q_{in} = total heat input available in test fuel charge in Btu (MJ)

WEIGHTED AVERAGE EMISSIONS AND EFFICIENCY – EPA METHOD 28WHH

$\eta_{avg} = \sum \eta_i \times F_i$, %
$E_{avg} = \sum E_i \times F_i$, lb/mmBTU$_{Output}$

Where:
η_{avg} = weighted average delivered efficiency in percent
F_i = weighting factor for heat output category

8-HR EMISSIONS AND EFFICIENCY – EPA METHOD 28WHH

$\eta_{avg\text{-}8h} = \eta_{del} + \{(8 - Y\,1) \times [(\eta_{del2} - \eta_{del1}) / (Y\,2 - Y\,1)]\}$, %
$Q_{out\text{-}8h} = [(\eta_{avg\text{-}8h} / 100) \times \{(X\,1 + X\,2) / 2\}]/8$, Btu/h

Where:
$\eta_{avg\text{-}8h}$ = Estimated Average Heat Output for 8 h burn time

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Q_{out-8h} = Efficiency for 8 h burn time
Y1 = test duration just above 8 h,
Y2 = test duration just below 8 h,
X1 = total heat input for duration Y1
X2 = total heat input for duration Y2
η_{del1} = average delivered efficiency for duration Y1
η_{del2} = average delivered efficiency for duration Y2

NOMENCLATURE FOR ASTM E2515:

A = Cross-sectional area of tunnel m2 (ft2).
B_{ws} = Water vapor in the gas stream, proportion by volume (assumed to be 0.02 (2.0 %)).
C_p = Pitot tube coefficient, dimensionless (assigned a value of 0.99).
c_r = Concentration of particulate matter room air, dry basis, corrected to standard conditions, g/dscm (gr/ dscf) (mg/dscf).
c_s = Concentration of particulate matter in tunnel gas, dry basis, corrected to standard conditions, g/dscm (gr/dscf) (mg/dscf).
E_T = Total particulate emissions, g.
F_p = Adjustment factor for center of tunnel pitot tube placement.
$F_p = V_{strav}/V_{scent}$
K_P = Pitot Tube Constant, 34.97 $\frac{m}{\sec}\left[\frac{\left(\frac{g}{g}\blacksquare mole\right)(mm\ Hg)}{(K)(mm\ water)}\right]^{\frac{1}{2}}$
or
= Pitot Tube Constant, 85.49 $\frac{ft}{\sec}\left[\frac{\left(\frac{lb}{lb}-mole\right)(in\ Hg)}{(R)(in\ water)}\right]^{\frac{1}{2}}$
L_a = Maximum acceptable leakage rate for either a pretest or post-test leak- check, equal to 0.0003 m3/min (0.010 cfm) or 4 % of the average sampling rate, whichever is less.
L_p = Leakage rate observed during the post-test leak-check, m3/min (cfm).
m_p = mass of particulate from probe, mg.
m_f = mass of particulate from filters, mg.
m_g = mass of particulate from filter gaskets, mg.
m_r = mass of particulate from the filter, filter gasket, and probe assembly from the room air blank filter holder assembly, mg.
m_n = Total amount of particulate matter collected, mg.
M_s = the dilution tunnel dry gas molecular weight (may be assumed to be 29 g/g mole (lb/lb mole).
P_{bar} = Barometric pressure at the sampling site, mm Hg (in. Hg).
P_g = Static Pressure in the tunnel (in. water).
P_R = Percent of proportional sampling rate.
P_s = Absolute average gas static pressure in dilution tunnel, mm Hg (in. Hg).
P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).
Q_{std} = Average gas flow rate in dilution tunnel.
$Q_{std} = 60\ (1 - B_{ws})\ V_s\ A\ [T_{std}\ P_s/T_s\ P_{std}]$

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dscm/min (dscf/min).

T_m = Absolute average dry gas meter temperature, K (R).

T_{mi} = Absolute average dry gas meter temperature during each 10-min interval, *i*, of the test run.

$$T_{mi} = (T_{mi(b)} + T_{mi(e)})/2$$

where:

$T_{mi(b)}$ = Absolute dry gas meter temperature at the beginning of each 10-min test interval, i, of the test run, K (R), and

$T_{mi(e)}$ = Absolute dry gas meter temperature at the end of each 10-min test interval, i, of the test run, K (R).

Ts = Absolute average gas temperature in the dilution tunnel, K (R).

Tsi = Absolute average gas temperature in the dilution tunnel during each 10-min interval, i, of the test run, K (R).

$$T_{si} = (T_{si(b)} + T_{m=si(e)})/2$$

where:

$T_{si(b)}$ = Absolute gas temperature in the dilution tunnel at the beginning of each 10-min test interval, i, of the test run, K (R), and

$T_{si(e)}$ = Absolute gas temperature in the dilution tunnel at the end of each 10-min test interval, i, of the test run, K (R).

V_m = Volume of gas sample as measured by dry gas meter, dcm (dcf).

V_{mc} = Volume of gas sampled corrected for the post test leak rate, dcm (dcf).

V_{mi} = Volume of gas sample as measured by dry gas meter during each 10-min interval, i, of the test run, dcm.

$V_{m(std)}$ = Volume of gas sample measured by the dry gas meter, corrected to standard conditions.

$$V_{m(std)} = K_1 V_m Y [(P_{bar} + (\Delta H/13.6))/T_m]$$

where:

K_1 = 0.3855 K/mm Hg for SI units and = 17.64 R/in. Hg for inch-pound units.

$$V_{m(std)} = K_1 V_{mc} Y [(P_{bar} + (\Delta H/13.6))/T_m]$$

where:

V_{mc} = Vm– (Lp– La)u

V_{mr} = Volume of room air sample as measured by dry gas meter, dcm (dcf), and

$V_{mr(std)}$ = Volume of room air sample measured by the dry gas meter, corrected to standard conditions.

$$V_{m(std)} = K_1 V_{mr} Y [(P_{bar} + (\Delta H/13.6))/T_m]$$

Where:

K_1 = 0.3855 K/mm Hg for SI units and = 17.64 R/in. Hg for inch-pound units, and

V_s = Average gas velocity in the dilution tunnel.

$$V_s = F_p K_p C_p (\surd\Delta P_{avg})(\surd(T_s/P_s M_s))$$

V_{si} = Average gas velocity in dilution tunnel during each 10-min interval, i, of the test run.

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$$V_{si} = F_p K_p C_p (\sqrt{\Delta P_i})(\sqrt{(T_{si}/P_s M_s)})$$

V_{scent} = Average gas velocity at the center of the dilution tunnel calculated after the Pitot tube traverse.
V_{strav} = Average gas velocity calculated after the multipoint Pitot traverse.
Y = Dry gas meter calibration factor.
ΔH = Average pressure at the outlet of the dry gas meter or the average differential pressure across the orifice meter, if used, mm water (in. water).
ΔP_{avg} = Average velocity pressure in the dilution tunnel, mm water (in. water).
ΔP_i = Velocity pressure in the dilution tunnel as measured with the Pitot tube during each 10-min interval, i, of the test run.

$$\Delta P_i = (\Delta P_{i(b)} + \Delta P_{i(e)})/2$$

where:
$\Delta P_{i(b)}$ = Velocity pressure in the dilution tunnel as measured with the Pitot tube at the beginning of each 10-min interval, i, of the test run, mm water (in. water), and
$\Delta P_{i(e)}$ = Velocity pressure in the dilution tunnel as measured with the Pitot tube at the end of each 10-min interval, i, of the test run, mm water (in. water).
θ = Total sampling time, min.
10 = ten min, length of first sampling period.
13.6 = Specific gravity of mercury.
100 = Conversion to percent.

TOTAL PARTICULATE WEIGHT – ASTM E2515

$$M_n = m_p + m_f + m_g$$

PARTICULATE CONCENTRATION – ASTM E2515

$$C_s = K_2(m_n/V_{m(std)}) \text{ g/dscm (g/dscf)}$$

where:
K_2 = 0.001 g/mg

TOTAL PARTICULATE EMISSIONS (g) – ASTM E2515

$$E_T = (C_s - C_r)Q_{std}\theta$$

PROPORTIONAL RATE VARIATION (%) – ASTM E2515

$$PR = [\theta(V_{mi} V_s T_m T_{si})/(10(V_m V_{si} T_s T_{mi})] \times 100$$

MEASUREMENT OF UNCERTAINTY – ASTM E2515

$$MU_{weighing} = \sqrt{0.1^2} \bullet X$$

GENERAL FORMULA – ASTM E2515

$$uY = \sqrt{((\delta Y/\delta x_1) \times u_1)^2 + \ldots + ((\delta Y/\delta x_n) \times u_n)^2}$$

Where:
$\delta Y/\delta x_i$ = Partial derivative of the combining formula with respect to individual measurement xi,
u_i = is the uncertainty associated with that measurement.

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TOTAL PARTICULATE EMISSIONS – ASTM E2515

$E_T = (c_s - c_r)\, Q_{std}\, \theta$

where:

c_s = sample filter catch/(sample flow rate x test duration), g/dscf,
c_r = room background filter catch/(sample flow x sampling time), g/dscf,
Q_{std} = average dilution tunnel flow rate, dscf/min, and
θ = sampling time, minutes.

MU OF c_s

$c_s = F_c/(Q_{sample} \text{ x } \theta) = 0.025/(0.25 \text{ x } 180) = 0.0005555$
$\delta c_s/\delta F_c = 1/Q_{sample} \bullet \Theta = 1/0.25 \bullet 180 = 0.0222$
$\delta c_s/\delta Q_{sample} = -F_c/Q^2{}_{sample} \bullet \Theta = -0.025/0.25^2 \bullet 180 = -0.00222$
$\delta c_s/\delta \Theta = -F_c/Q_{sample} \bullet \Theta^2 = -0.025/0.25 \bullet 180^2 = -0.000003$
$MUc_s = \surd(0.00027 \bullet 0.0222)^2 + (0.0025 \bullet - 0.00222)^2$
$\surd + (0.1 \bullet - 0.000003)^2 = 0.0000091\text{g}$
Thus, c_s would be 0.555 mg/dscf ± 0.0081 mg/dscf at 95% confidence level.

MU OF c_r

$c_r = BG_c/(QBG \text{ x } \theta) = 0.002/(0.15 \text{ x } 180) = 0.000074$
$\delta c_r/\delta BG_c = 1/Q_{BG} \bullet \Theta = 1/0.15 \bullet 180 = 0.03704$
$\delta c_r/\delta Q_{BG} = -BG_c/Q^2{}_{BG} \bullet \Theta = -0.002/0.15^2 \bullet 180 = -0.0004938$
$\delta c_r/\delta \Theta = -BG_c/Q_{BG} \bullet \Theta^2 = -0.002/0.15 \bullet 180^2 = -0.0000004$
$MUc_r = \surd(0.00027 \bullet 0.03704)^2 + (0.0015 \bullet - 0.0004938)^2$
$\surd + (0.1 \bullet - 0.0000004)^2 = 0.00001\text{g}$
Thus, c_r would be 0.074 mg/dscf ± 0.01 mg/dscf at 95% confidence level.

E_T AND MU_{ET}

$E_T = (c_s - c_r)\, Q_{sd}\, \theta = (0.000555 - 0.000074) \text{ x } 150 \text{ x } 180 = 13.00\text{g}$
$\delta E_T/\delta c_s = Q_{std} \bullet \Theta = 150 \bullet 180 = 27{,}000$
$\delta E_T/\delta c_r = Q_{std} \bullet \Theta = 150 \bullet 180 = 27{,}000$
$\delta E_T/\delta Q_{std} = c_s \bullet \Theta - c_r \bullet \Theta = 0.000555 \bullet 180 - 0.000074 \bullet 180 = 0.08667$
$\delta E_T/\delta \Theta = c_s \bullet Q_{std} - c_r \bullet Q_{std} = 0.000555 \bullet 180 - 0.000074 \bullet 180 = 0.07222$
$MU_{ET} = \surd(27{,}000 \bullet 0.0000081)^2 + (27{,}000 \bullet 0.00001)^2\ (0.08667 \bullet 3)^2$
$\surd + (0.07222 \bullet 0.1)^2 = 0.436$

Thus the result in this example would be:
ET = 13.00g ± 0.44 g at a 95% confidence level.

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EFFICIENCY – CSA B415.1

The change in enthalpy of the circulating air shall be calculated using the moisture content and temperature rise of the circulating air, as follows:

$$\Delta h = \Delta t\ (1.006 + 1.84x)$$

Where:
Δh = change in enthalpy, kJ/kg
Δt = temperature rise, °C
1.006 = specific heat of air, kJ/kg °C
1.84 = specific heat of water vapor, kJ/kg °C
x = humidity ratio, kg/kg

The equivalent duct diameter shall be calculated as follows:

$$ED = 2HW/H+W$$

Where:
ED = equivalent duct diameter
H = duct height, m
W = duct width, m

The air flow velocity shall be calculated as follows:

$$V = F_p \times C_p \times 34.97 \times \sqrt{}T/28.56(P_{baro} + P_s)$$

where
V = velocity, m/s
F_P = Pitot tube calibration factor determined from vane anemometer measurements
C_P = Pitot factor
= 0.99 for a standard Pitot tube or as determined by calibration for a Type S Pitot tube
34.97 = Pitot tube constant
Note: The Pitot tube constant is determined on the basis of the following units: $m/s[g/g\ mole\ (mm\ Hg)/(K)(mm\ H_2O)]^{0.5}$
ΔP = velocity pressure, mm H2O
T = temperature, K
28.56 = molecular weight of air
P_{Baro} = barometric pressure, mm Hg
P_s = duct static pressure, mm Hg

The mass flow rate shall be calculated as follows:

$$m = 3600VAp$$

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where:

m = mass flow rate, kg/h
V = air flow velocity, m/s
3600 = number of seconds per hour
A = duct cross-sectional area, m2
p = density of air at standard temperature and pressure (use 1.204 kg/m3)

The rate of heat release into the circulating air shall be calculated using the air flow and change in enthalpy, as follows:

$$\Delta e = \Delta h \times m$$

Where:

Δe = rate of heat release into the circulating air, kJ/h
Δh = change in enthalpy of the circulating air, kJ/kg
m = mass air flow rate, kg/h

The heat output over any time interval shall be calculated as the sum of the heat released over each measurement time interval, as follows:

$$E_t = \sum(\Delta e \times i) \text{ for } i = t_1 \text{ to } t_2$$

Where:

Et = delivered heat output over any time interval $t_2 – t_1$, kJ
i = time interval for each measurement, h

The average heat output rate over any time interval shall be calculated as follows:

$$e_t = E_t / t$$

where

e_t = average heat output, kJ/h
t = time interval over which the average output is desired, h

The total heat output during the burn shall be calculated as the sum of all the heat outputs over each time interval, as follows:

$$E_d = \sum(E_t) \text{ for } t = t_0 \text{ to } t_{final}$$

Where:

E_d = heat output over a burn, kJ/h (Btu/h)
E_t = heat output during each time interval, kJ/h (Btu/h)

The efficiency shall be calculated as the total heat output divided by the total energy input, expressed as a percentage as follows:

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Efficiency, % = 100 × E_d/I

Where:

E_d = total heat output of the appliance over the test period, kJ/kg

I = input energy (fuel calorific value as-fired times weight of fuel charge), kJ/kg (Btu/lb)

SECTION 9
TEST SPECIMEN DESCRIPTION

The model SE210 Solid Fuel Hydronic Heater is constructed of sheet steel, stainless steel, and refractory. The outer dimensions are 50-inches deep, 68-inches high, and 33-inches wide. The unit has a door located on the front.

SECTION 10
TEST RESULTS

DESCRIPTION OF TEST RUNS:

RUN #1 (9/21/21): The heater was set to draw a category 4 output rate. The test load weighed 79.8 lbs. and utilized a 15 lb. coal bed. The average Btu/hr. output was 155,802. Burn time was 3.1 hours. The kg/hr. burn rate was 9.42.

RUN #2 (9/22/21): The heater was set to draw a category 1 output rate. The Test load weighed 86.4 lbs. and utilized a 11 lb. coal bed. The average Btu/hr. output was 23,858. Burn time was 14.02 hours. The kg/hr. burn rate was 2.28.

RUN #3 (9/23/21): The heater was set to draw a category 2 output rate. The Test load weighed 76.7 lbs. and utilized a 12 lb. coal bed. The average Btu/hr. output was 39,042. Burn time was 9.75 hours. The kg/hr. burn rate was 2.91.

RUN #4 (8/7/20): The heater was set to draw a category 3 output rate. The test load weighed 76.5 lbs. and utilized a 12 lb. coal bed. The average Btu/hr. output was 74,281. Burn time was 5.12 hours. The kg/hr. burn rate was 5.57.

All test runs have been found to be appropriate, with no anomalies, and each test run has been validated and are deemed compliant. No negative weight was found on the filters, as the filters and gaskets are weighed together to eliminate filter material transfer to gaskets. All weightings were handled property, with no negative weight on gaskets or probes. All test loads were loaded in a north/south configuration.

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TABLE 1 – DATA SUMMARY PART A

Cat	Run No.	Load % Capacity	Target Load	Actual Load	Actual Load	Test Duration	Wood Weight as-fired	Wood Moisture	Heat Input	Heat Output
			Btu/hr	Btu/hr	% of Max	hrs	lb	% DB	Btu	Btu
1	2	<15% of Max	25,500	23,858	14.0%	14.02	86.41	22.59	606,180	334,410
2	3	16-24% of Max	40,800	39,042	23.0%	9.75	76.71	22.67	537,811	380,659
3	4	25-50% of Max	85,000	74,281	43.7%	5.12	76.46	21.70	540,310	380,072
4	1	Max capacity	170,000	155,802	91.6%	3.13	79.80	22.58	559,866	488,180

TABLE 2. – DATA SUMMARY PART B

Category	Run No.	Load % Capacity	Min Return Water Temp.	Total PM Emissions	PM Output Based	PM Output Based	PM Rate	PM Factor	Delivered Efficiency	Stack Loss Efficieny	1st Hour Emissions
			°F	g	lb/mmBtu Out	g/MJ	g/hr	g/kg	%	%	Lb/mmBtu Out
1	2	<15% of Max	162.61	23.18	0.153	0.066	1.65	0.72	55.2%	36.8%	0.07
2	3	16-24% of Max	159.62	24.81	0.144	0.062	2.55	0.87	70.8%	73.2%	0.04
3	4	24-50% of Max	157.15	18.89	0.110	0.047	3.69	0.66	70.3%	76.6%	0.06
4	1	Max capacity	132.48	15.25	0.069	0.030	4.87	0.52	87.2%	80.0%	0.00

TABLE 3 – AVERAGED DATA

Category	Run No.	Weighting Factor	Delivered Efficiency	Emissions g/hr	Stack Loss Efficiency	CO Emissions g/min
1	2	0.25	0.138	0.41	0.092	0.965
2	3	0.25	0.177	0.64	0.183	1.023
3	4	0.25	0.176	0.92	0.192	1.205
4	1	0.25	0.218	1.22	0.200	1.295
Totals		**1.000**	**70.9%**	**3.19**	**66.6%**	**4.49**

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TABLE 4 - CSA B415.1 STACK LOSS RESULTS

Category	RUN NO.	CO EMISSIONS (g/min)	HEATING EFFICIENCY (% HHV)	HEAT OUTPUT (Btu/hr)
1	2	3.86	36.8	15,552
2	3	4.09	73.2	40,161
3	4	4.82	76.6	80,537
4	1	5.18	80.0	142,326

TABLE 5 – SAMPLING PRECISION RESULTS

Category	RUN NO.	EMISSIONS (g/hr)	DEVIATION (%)	DEVIATION (g/kg)
1	2	1.65	3.77	0.05
2	3	2.55	9.49	0.17
3	4	3.69	1.20	0.02
4	1	4.87	18.85	0.19

SECTION 11
CONCLUSION

This test demonstrates that this unit is an affected facility under the definition given in the regulation. The emission rates of:
0.15 lb./MMBtu – Output (Cat 1)
0.14 lb./MMBtu – Output (Cat 2)
0.11 lb./MMBtu – Output (Cat 3)
0.07 lb./MMBtu – Output (Cat 4)
meets the EPA requirements for the Step 2 limits.

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SECTION 12
PHOTOGRAPHS

Photo No. 1
Test #1

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Photo No. 2
Test #2

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Photo No. 3
Test #3

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Photo No. 4
Test #4

Photo No. 5
Sealing #1

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Photo No. 6
Sealing #2

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TEST REPORT FOR ALTERNATE HEATING SYSTEMS
Report No.: 104711998MID-007R2
Date: 3/9/22

SECTION 13
REVISION LOG

REVISION #	DATE	PAGES	REVISION
0	09/29/21	N/A	Original Report Issue
1	11/22/21	2, 3	Corrected edition date for ASTM E2618 from 2017 to 2013 (R2019).
2	3/9/22	20	Added Table 5 – Sampling Precision Results to Section 10.