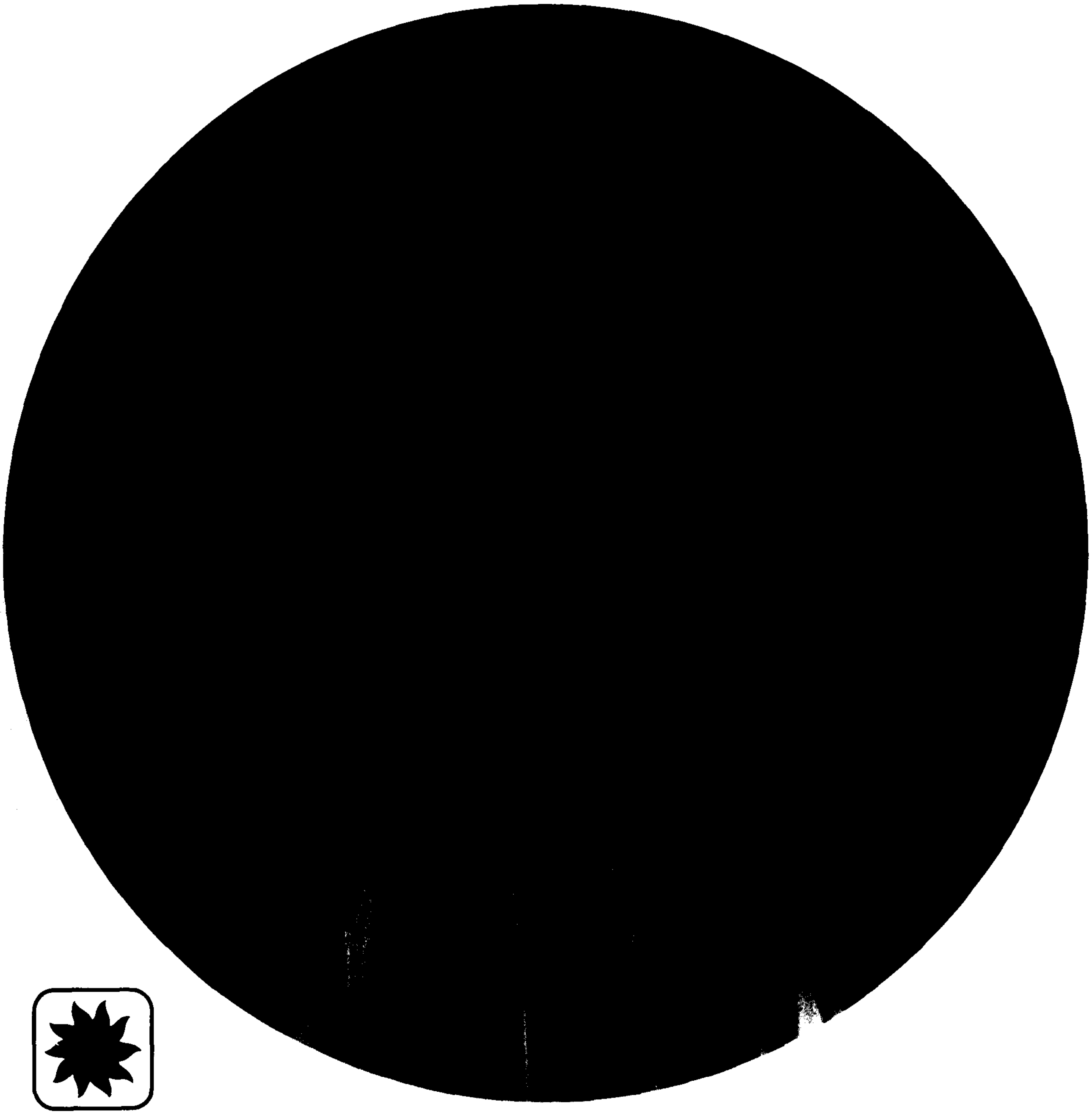
CAN/CSA-B415.1-92

Performance Testing of Solid-Fuel-Burning Stoves, Inserts, and Low-Burn-Rate Factory-Built Fireplaces

A National Standard of Canada



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General
Instruction No. 1
CAN/CSA-B415.1-92
April 1992

CSA Standard **CAN/CSA-B415.1-92**, ***Performance Testing of Solid-Fuel-Burning Stoves, Inserts, and Low-Burn-Rate Factory-Built Fireplaces,*** consists of 77 pages, each dated April 1992.

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CAN/CSA-B415.1-92

National Standard of Canada CAN/CSA-B415.1-92

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Preface

This is the first edition of CSA Standard CAN/CSA-B415.1, *Performance Testing of Solid-Fuel-Burning Stoves, Inserts, and Low-Burn-Rate Factory-Built Fireplaces*. It supersedes Preliminary Standard B415, *Performance Testing of Solid Fuel Burning Appliances,* published in September 1986. It is anticipated that this Standard will be followed by CSA Standards CAN/CSA-B415.2, *Performance Testing of Solid-Fuel-Burning Central Systems* and CAN/CSA-B415.3, *Performance Testing of Site-Built and Decorative Fireplaces, and Large Factory-Built Fireplaces.*

This Standard has been developed to assist manufacturers in developing solid-fuel-burning appliances with improved combustion characteristics, and at the request of government authorities so that they can regulate appliances in new installations.

This Standard uses SI (metric) units. It describes a test procedure for measuring the emissions, heat output, and efficiency of free-standing, solid-fuel-burning stoves and inserts, factory-built fireplaces having a minimum fuel input less than 5 kg/h, and automatically-fuelled stoves. Factory-built fireplaces with a greater burn rate are excluded, as are central systems, particulate-fired systems other than those noted above, and site-built fireplaces. The Committee has striven to make B415 methodology consistent with EPA methodology.

The emissions test procedure contained herein can be applied to most wood-fired appliances. However, emissions expressed in grams per hour, intended to provide compatibility with EPA requirements for space heaters with a maximum burn rate less than, or equal to, 5.3 kg/h, cannot be readily determined for some appliances such as high mass systems or heat storage units. For these types of appliance, as well as for units with burn rates equal to or above 5 kg/h, emission limits expressed in g/MJ of heat input have been developed.

This Standard was prepared by the Technical Committee on Performance Testing and Rating of Solid-Fuel-Burning Appliances under the jurisdiction of the Standards Steering Committee on Fire Safety and Fuel Burning Equipment. It has been approved as a National Standard of Canada by the Standards Council of Canada.

April 1992

Notes:

(1) Use of the singular in this Standard does not exclude the plural (and vice versa) when the sense allows.

(2) Although the intended primary application of this Standard is stated in its Scope, it is important to note that it remains the responsibility of the users of the Standard to judge its suitability for their particular purpose.

(3) CSA Standards are subject to periodic review, and suggestions for their improvement will be referred to the appropriate committee.

(4) All enquiries regarding this Standard, including requests for interpretation, should be addressed to Canadian Standards Association, Standards Division, 178 Rexdale Boulevard, Rexdale, Ontario M9W 1R3.

Requests for interpretation should

(a) define the problem, making reference to the specific clause, and, where appropriate, include an illustrative sketch;

(b) provide an explanation of circumstances surrounding the actual field condition; and

(c) be phrased where possible to permit a specific "yes" or "no" answer.

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CAN/CSA-B415.1-92 Performance Testing of Solid-Fuel-Burning Stoves, Inserts, and Low-Burn-Rate Factory-Built Fireplaces

1. Scope

1.1

This Standard specifies requirements for the performance testing of solid-fuel-burning appliances. It prescribes a method for determining heat outputs, appliance efficiencies, emission levels and composition, and flue gas flow rates for solid-fuel-fired appliances. The Standard also specifies maximum emission rates.

1.2

For the purpose of this Standard, solid-fuel-burning appliances shall include
(a) manually and automatically fuelled stoves, space heaters, fireplace inserts; and
(b) factory-built fireplaces with a minimum burn rate less than 5 kg/h.

1.3

For the purpose of this Standard, the term “solid-fuel” includes biomass fuels such as cordwood, chips, sawdust, peat “logs”, wood and paper pellets, and kernel corn. It does not include coal.

1.4

The efficiency determination and the related labelling requirements are not applicable to appliances which are designed so that at least a portion of the heat generated is available for purposes other than space heating.

2. Reference Publications

2.1

This Standard refers to the following publications and where such reference is made it shall be to the edition listed below, including all amendments published thereto.

ASTM* Standards

D2015-85 (Reapproved 1978),
Gross Calorific Value of Solid Fuel by the Adiabatic Bomb Calorimeter;

D2016-74 (Reapproved 1983),
Moisture Content of Wood;

D3154-72,
Average Velocity in a Duct (Pitot Tube Method);

D3286-82,
Cross *Calorific Value of Cool and Coke by the Isothermal Bomb Calorimeter;*

D4442-84,
Test Methods *for* Direct *Moisture* Content Measurement *of Wood and Wood-Base Materials;*

D4444-84,
Test Methods for Use and Calibration of Hand-Held Moisture Meters.

Standards Council of Canada
CAN-I 5106,
Guidelines *for Preparing an Application for Accreditation Organizations.*

Environment Canada
Report EPS 1-AP-74-1,
Standard Reference Methods (A to E) for Source Testing.

Environmental Protection Agency (USA)
New Source *Performance Standards, Title 40, Part 60, Sub-part AAA of the Code of Federal Regulations, Methods 5 and 28.*

ULC† Standard
CAN/ULC-S629-M1987,
650°C *Factory-Built Chimneys.*

'American Society for Testing and Materials.
† Underwriters' Laboratories of Canada.

3. Definitions

3.1

The following definitions apply in this Standard.

Air-fuel ratio — the ratio of the mass of dry combustion air introduced into the firebox to the mass of dry fuel consumed.

Appliance — a device to convert the energy in fuel to useful heat, and includes all components, controls, wiring, and piping required by the applicable Standard to be part of the device.

Appliance, automatically controlled — an appliance provided with a sensor or sensors that act to control the heat output.

Appliance, free-standing — an appliance intended for installation in a room in such a manner that it is exposed to the room on all sides, and intended to deliver heat without ducts or plumbing.

Appliance label — a sheet (or sheets) of metal, affixed to an appliance, that displays the information required by this Standard.

Appliance, manually controlled — an appliance not provided with automatic controls.

Ash — solid inert components of the fuel which remain in the appliance.

Boiler — an appliance intended to supply hot water or steam for space heating, process heat, or power purposes.

Burn cycle — the period of time between the loading of a fuel charge and the loss of the total charge weight except ash.

Burn rate -the weight of the dry fuel charge (weight of any moisture excluded) divided by the burn cycle time.

Catalytic **appliance** — an appliance which incorporates a catalytic combustor.

Catalytic comburtor — a substrate coated with a chemical substance whose presence *results* in a decrease *in* flue gas ignition temperature.

Charcoal — reactive components of the fuel remaining in the appliance after the volatiles have been released.

Chimney — a primarily vertical shaft enclosing at least one flue for conducting flue gases to the outside atmosphere.

Cordwood — conventional firewood, often referred to as "roundwood" although, in practice, it is usually roundwood, 300 to 600 mm long, that has been split by an axe into segments. There is no equivalent SI term to the Imperial measure of Cord.

Creosote — organic components of the flue gas, in solid or liquid form, that deposit on the inside of the flue or vent.

Dilution tunnel, noncondensing — an apparatus for dilution of the flue gas flow from an appliance, and collection on filters of all the **particulates** carried by a representative sample of this flow during an entire burn.

Draft -the potential for flow of air or combustion gases, or both, through an appliance and its venting system, normally measured as static pressure.

Note: ***Draft is indicated by the difference between the pressure at a specified point in the appliance or venting system and the pressure of the air at the same elevation outside the appliance or venting system. The term "natural draft" signifies that no fan is used to maintain or accelerate the draft.***

Efficiency (overall or appliance) is calculated as follows:

$$\text{Efficiency} = \frac{Eo}{Et}$$

where

Eo = usable energy output of appliance

Et = total energy content of the fuel consumed (based on higher heating value)

Emissions, **particulate** — components of the flue gas, in solid or liquid phase (excluding water), that can be collected on a 0.3 m filter.

Energy Input rate — the rate at which thermal energy is delivered to the appliance, calculated on the basis of the higher (or gross) heating value of the as-fired fuel.

Fire chamber (or **firebox)** -an enclosure in which the test fuel charge is placed and combusted.

Fireplace, factory-built — a fire chamber and its chimney, consisting entirely of factory-made parts designed for unit assembly without requiring field construction. A factory-built fireplace may also include combustion-air and warm-air ducts, grills, and accessories.

Fireplace insert — an appliance intended for insertion into a fireplace cavity.

Flue — an enclosed passageway within an appliance for conveying combustion products and excess air. See "Vent".

Flue pipe (chimney connector) -the conduit connecting the flue collar of an appliance to a chimney.

Furnace — a central system space-heating appliance that uses warm air as the heating medium, and has provision for the attachment of ducts.

Higher heat value — the heat generation potential of a moisture-free fuel, including the latent heat contained in any moisture produced by its reaction.

Kiln-dried lumber — lumber that has been placed in a kiln and exposed to a current of hot air for the purpose of accelerating the evaporation of moisture.

Moisture content (dry basis) - the weight of water in wood, divided by the weight of the dry wood only (oven-dry weight), expressed as a percentage, ie, MC%db, where "db" stands for "dry basis".

Moisture content (wet basis) - the weight of water in wood, divided by the combined weight of the water plus the wood (green weight), expressed as a percentage, ie, MCwb%, where "wb" stands for "wet basis".

Note: ***It is sometimes necessary to convert from wet basis to the dry basis (which is usually used for lumber), as follows:***

$$MCdb\% = \frac{MCwb \times 100}{100 - (MCwb \times 100)}$$

or from dry basis to wet basis, as follows:

$$MCwb\% = \frac{MCdb \times 100}{100 + (MCdb \times 100)}$$

Noncatalytic — an appliance that does not incorporate a catalytic combustor in the combustion system.

Particulate emissions — air-borne solids generated by combustion.

Particulate fuels - those fuels which are intended to be used in particulate or divided form, the size of the individual particles falling within a prescribed range; the term includes chips, pellets, and kernel corn.

Pelletized fuel — processed fuel consisting of uniform, discrete pellets of compressed, dried material.

Regulatory authority — the governmental body responsible for the enforcement of any part of this Standard or the official or agency designated by that body to exercise such a function.

Stove — an appliance intended for space heating, cooking, or both.

Usable firebox volume - the space within a **firebox** that can be utilized to store conventional firewood loaded in a practical manner. It is not affected by any suggested loading limit that may be marked on the appliance.

Vent — an enclosed passageway, exterior to the appliance, for conveying combustion products and excess air to a discharge point.

4. Emission Requirements

4.1 Particulate Emissions

4.1.1

The particulate emission rate, for any test run that is required to be used in determining the average emissions, shall be determined in accordance with the procedures described in

Clauses 5 to 10, and shall not exceed:
(a) for an appliance not equipped with a catalytic combustor:
  (i) 12.7 g/h for burn rates ≤ 1.5 kg/h;
  (ii) 15.8 g/h for burn rates 1.5 kg/h but ≤ 8.3 kg/h; or
  (iii) 0.096 g/MJ (input) for burn rates > 8.3 kg/h; and
(b) for an appliance equipped with a catalytic combustor:
  (i) $(1.95 \bullet BR + 2.74)^{1.205}$ g/h for burn rates ≤ 2.82 kg/h;
  (ii) 12.7 g/h for burn rates > 2.82 kg/h but ≤ 6.7 kg/h; or
  (iii) 0.096 g/MJ (input) for burn rates 6.7 kg/h
where BR is the dry fuel burn rated in kg/h.

4.1.2

The average particulate emission rate, as determined in Clause 10.9, shall be equal to or less than:
(a) for catalytic combustor equipped appliances:
  (i) 2.7 g/h for appliances with a maximum burn rate at or below 5.3 kg/h; or
  (ii) the greater of 2.7 g/h or 0.096 g/MJ (input) for appliances with a maximum burn rate above 5.3 kg/h; and
(b) for appliances not equipped with a catalytic combustor:
  (i) 5.5 g/h for appliances having a maximum burn rate at or below 5.3 kg/h; or
  (ii) the greater of 5.5 g/h or 0.096 g/MJ (input) for appliances with a maximum burn rate above 5.3 kg/h.

Note: *The g/h values include the EPA correction factor for dilution tunnel sampling, eg, the 5.5 g/h noncatalytic rate of CAN/CSA-B415. I is equivalent to the EPA rate of 7.5* g/h.

4.2 CO Emissions

Carbon monoxide emissions, as determined by Clause 10.12, for any test run that is required to be used in the weighted average particulate emission results, shall not exceed 13.5 g/MJ.

5. Test Facilities

5.1 Test Room

5.1.1

The room shall be free of drafts such that air velocities will be less than 0.25 m/s within 1 m of the appliance when the appliance is not operating. The flue shall discharge into the same space or into a space freely communicating with the test room. Any draft hood or similar device used for final venting of the combustion products shall not impose a draft greater than 1.25 Pa on the appliance flue when the appliance is not operating.

5.1.2

The temperature in the test room shall be maintained between 18 and 32°C during the tests. Any ventilation required to achieve this requirement shall not violate the draft conditions of Clause 5.1 .1.

5.1.3

The barometric pressure in the test room shall not exceed 103 kPa during any test run if the test is conducted in a pressurized facility.

5.2 Appliance Installation and Preparation

5.2.1

The appliance shall be installed in accordance with the manufacturer's installation and operation instruction manual.

5.2.2

The flue pipe for the appliance shall be made of black-painted steel or equivalent black-painted material. Any cracks or joints shall be sealed with furnace cement or equivalent. The flue pipe diameter shall match the flue collar of the appliance. Other flue pipe may be used if the appliance manufacturer's listed instructions require such a flue pipe for home installations.

5.2.3

The flue pipe shall vent into a vertical solid-pack-type factory-built chimney conforming to ULC Standard CAN/ULC 5629, beginning 2.6 ± 0.15 m above the platform and extending to a point 4.6 ± 0.3 m above the platform on which the appliance is resting. Other chimney types may be used if the appliance manufacturer's listed instructions require such a chimney for home installations. The inside diameter of the factory-built chimney shall be in accordance with the manufacturer's instructions, except that it shall not be less than the diameter of the appliance flue collar.

5.2.4

Record the test fuel charge dimensions and weights, and the appliance and catalyst descriptions. (The form shown in Figure 6 or equivalent may be used.) For catalyst-equipped appliances, measure the size of the gap(s) around the bypass door in the closed position that would allow the leakage of combustion products into the flue.

5.2.5

An appliance shall be operated before the test procedures of Clause 7 are carried out, using the fuel described in Clause 7 or cordwood having a moisture content between 15 and 25% wet basis as follows:

(a) for noncatalytic appliances, operate the appliance at a medium burn rate (burn-rate Category 2 or 3, as defined in Clause 8) for at least 10 h; and

(b) for catalyst-equipped appliances, install a new catalyst and operate the appliance at least a medium burn rate for at least 50 h while maintaining the catalyst exit temperature above 260°C. Record and report hourly catalyst exit temperature data (see Clause 5.2.6) and the hours of operation.

5.2.6

For catalyst-equipped appliances, an optional temperature monitor may be installed about 25 mm upstream of the catalyst at the centroid of the catalyst face area. A temperature monitor to measure the catalyst exhaust temperature shall be centrally located within 25 mm downstream of the catalyst at the centroid of catalyst face area. Record temperature monitor locations.

5.2.7

Locate appliance surface temperature monitors at five locations on the appliance firebox

exterior surface. Position the temperature monitors centrally on the top surface, on two sidewall surfaces, and on the bottom and back surfaces. Position the monitor sensing tip on the firebox exterior surface inside of any heat shield, air circulation walls, or other wall or shield separated from the firebox exterior surface. Surface temperature locations for unusual design shapes (eg, spherical, etc) shall be positioned so that there are four surface temperature monitors in both the vertical and horizontal planes passing at right angles through the centroid of the firebox, not including the fuel loading door (total of five temperature monitors).

6. Test Instrumentation and Apparatus

6.1 Fuel Characteristics

6.1.1 Fuel Weight

The weight of wood consumed during a burn shall be determined by a device capable of measuring to within 0.05 kg or 1% of the initial test fuel charge weight, whichever is greater.

6.1.2 Fuel Moisture Content

The wood moisture content shall be determined using the equipment referenced in Clause 7.2.2.

6.1.3 Fuel Calorific Value

The calorific value of the fuel shall be determined using the equipment referenced in Clause 7.2.4.

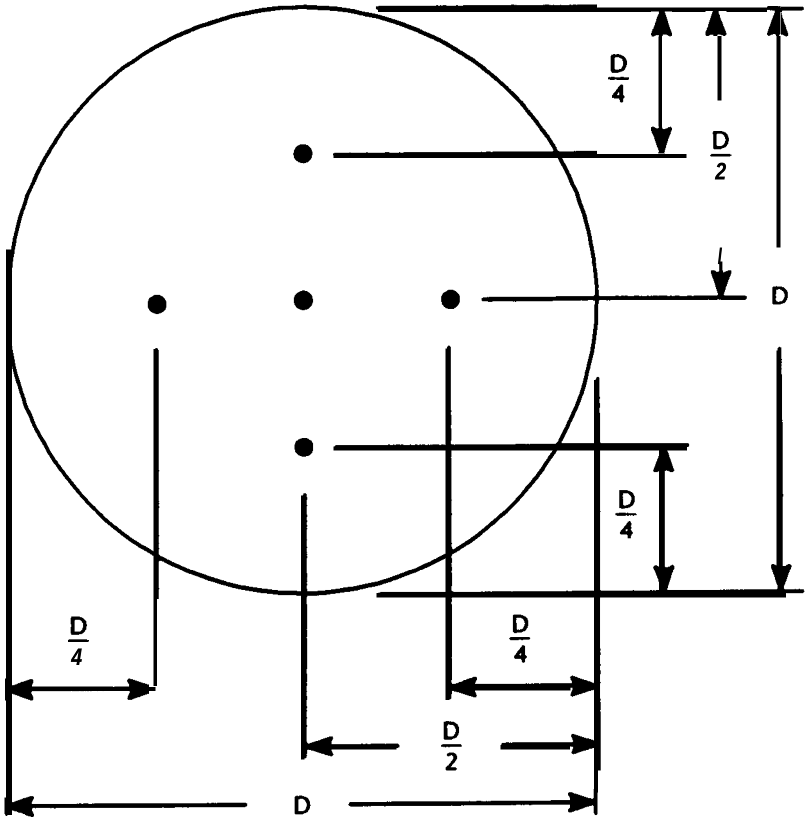
6.2 Temperatures

6.2.1 Air Temperature

The air temperature in the test room shall be measured by means of a 24 gauge, type J thermocouple, or equivalent. The thermocouple shall be located centrally within a vertically-oriented steel pipe, 150 mm long and 50 mm in diameter, open at both ends. The thermocouple and shield shall be located on the same horizontal plane as the primary air intake openings of the heater. The thermocouple shall be not closer than 1 m and not further than 2 m from the appliance.

6.2.2 Flue Gas Temperature

The flue gas temperature shall be determined by means of an array of five 24 to 30 gauge, type K, sheathed thermocouples or equivalent, located 150 ± 15 mm above the base of the chimney (as described in Clause 5.2.3). The thermocouples shall be located as shown in Figures 1 and 2.



Chimney cross-section

Note: • = thermocouple.

Figure 1
Location of Thermocouples in Chimney

6.2.3 Accuracy of Temperature-Measuring Equipment

The accuracy of the temperature-measuring equipment shall be within ±1.5% of absolute temperature.

6.3 Flue Gas Composition

6.3.1

Oxygen, carbon monoxide, and carbon dioxide (0,, CO, and CO,) shall be measured. The percentage of CO, and CO in the flue gas shall be measured by means of an Orsat analyzer, continuous infrared analyzer, or equivalent analysis equipment. Oxygen shall be measured using an Orsat analyzer, paramagnetic analyzer, thermomagnetic analyzer, or equivalent analysis equipment. Zirconium oxide type oxygen analyzers shall not be used. If Orsat analysis is used, a sulphate solution shall be used for CO rather than cuprous chloride. Continuous analyzers shall provide a minimum accuracy and repeatability, and maximum zero and span drift over a 24 h period, of 1% of full scale.

6.3.2

Gas samples shall be taken by means of a probe inserted at the centreline of the chimney, 50 mm above the thermocouples measuring flue gas temperature. The probe shall conform to the requirements of Clause 6.5.11.

6.3.3

The sampling train of continuous analyzers shall be so arranged that all instruments reach 90% of their final reading within 30 s when responding to a calibration gas of at least 80% of full scale and beginning at ambient levels. The calibration gas for this test shall be introduced via the sampling probe.

6.3.4

If data are recorded automatically, the value recorded shall be the average of at least two readings taken over an interval of at least 20 s.

6.4 Miscellaneous

6.4.1

Elapsed time shall be measured with a device capable of accurately measuring to 0.07% of the test duration.

6.4.2

Ambient humidity shall be measured using a psychrometer, hygrometer, or device of equal or greater accuracy.

6.4.3

Barometric pressure shall be measured using a mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg.

6.4.4

Dilution tunnel flow velocity shall be determined using an S-type pitot tube and inclined manometer, accurate to within 5%.

6.5 Particulate Sampling System

6.5.1

The equipment used for measuring particulate emissions shall consist of a sample-conditioning system and a sample collection system. Figure 2 is a schematic of the sample-conditioning system. Figure 3 is a schematic of the particulate sample collection system.

6.52

The sample-conditioning system shall include a collection hood, a dilution tunnel, a blower and flow rate control system, and a thermocouple.

6.5.3

The collection hood and dilution tunnel should be made of electrically conductive material that is grounded, does not react with the exhaust components, and does not contribute particulate or condensable material to the test gas mixture.

6.5.4

The collection tunnel hood shall be constructed of steel with a minimum diameter of 0.3 m on the large end and a coupling capable of connecting to standard 0.15 to 0.3 m stove pipe on the small end.

6.5.5

The dilution tunnel shall be circular in cross-section, incorporate at least two 90° elbows upstream of the sampling section, and be not more than 9.1 m in length, measured along the tunnel axis, from the hood inlet to the sampling probe hole. The tunnel should be 0.15 to 0.3 m in diameter; however, a larger diameter may be used if necessary to satisfy dilution ratio requirements of Clause 6.5.8 or to avoid blockage of the filters due to excessive particulate loading or to avoid excessive velocity.

6.5.6

Two steel semicircular discs attached at 90° to the dilution tunnel axis on opposite sides of the dilution tunnel duct shall be installed midway between the two elbows upstream of the sampling section. The distance between these baffles shall be about 300 mm.

6.5.7

The sampling section of the dilution tunnel shall consist of two velocity traverse measurement ports located at 90° to each other and at least 1.2 m downstream of the elbow after the mixing section, plus a sampling probe port located at least 1.2 m downstream of the velocity measurement ports.

6.5.8

The sampling section velocity shall be 220 ± 25 m/min unless higher flow velocities are necessary to avoid excessive particulate filter loadings. If higher velocities or larger dilution tunnel diameters are used, it is recommended that the ratio of the average mass flow rate in the dilution tunnel to the average fuel burn rate be less than 150:1.

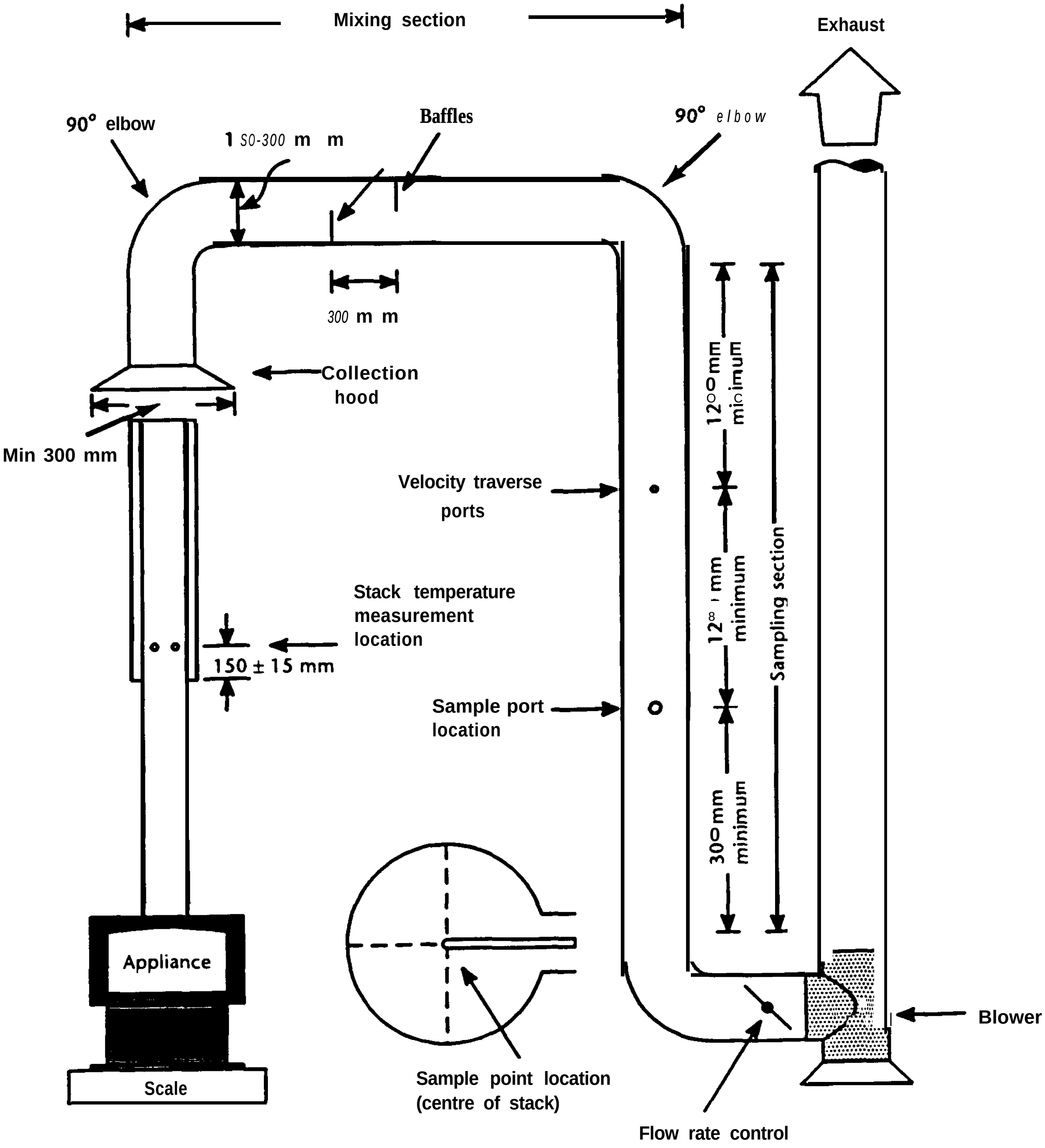


Figure 2
Suggested Construction Details of the Sample-Conditioning System

6.5.9

The temperature in the dilution tunnel shall be measured with a thermocouple having an accuracy of ±1.6°C in the range of 15–52°C.

6.5.10

The sample collection system shall consist of a probe, filters and filter holders, and a system for inducing and measuring the sample flow (see Figure 3 for typical system).

6.5.11

The sample probe shall comply with the following:
(a) the probe opening shall be located near the tunnel centerline (within 10% of the tunnel diameter) at least 1.2 m from the velocity measurement apparatus;
(b) the probe shall be a sharp edged nozzle with an inside diameter of approximately 9.5 mm; and
(c) the probe and all connecting tubing shall be made of glass or seamless stainless steel.

6.5.12

Two filter holders in series shall be used which shall comply with the following:
(a) be made of borosilicate glass, stainless steel, or Teflon®, with a glass frit or stainless steel filter support and a silicone rubber, Teflon@, or Viton® gasket;
(b) the filter holder shall provide a positive seal against leakage from the outside or around the filter;
(c) the backup filter holder shall be located 25–100 mm downstream from the primary filter holder; and
(d) the filter holder shall be capable of holding a filter with a 100 mm diameter.

6.5.13

The filter temperature shall be measured at the inlet or exit side of the front filter holder so that the sensor, or the thermowell used with the sensor, is in direct contact with the sample gas.

6.5.14

The particulate filters shall
(a) be of glass fibre;
(b) have a minimum diameter of 100 mm;
(c) not contain organic binder; and
(d) have a collection efficiency of at least 99.95% (<0.05% penetration by 0.3 µm dioctyl phthalate smoke particles).

Note: *Gelman A/E 61631 have been found acceptable for this purpose.*

7. Fire Chamber Measurement and Fuelling for Cordwood-Fired Appliances

7.1 Fire Chamber Volume

7.1.1

The volume of a fire chamber is calculated in the appropriate manner, eg, the volume of a rectilinear firebox is the product of the fire chamber length, width, and height.

7.1.2

For test purposes, fire chamber length is the greater fire chamber floor dimension that is parallel to a wall of the chamber; fire chamber width is the shortest fire chamber floor dimension that is parallel to a wall of the chamber; and fire chamber height is the lesser of the distance from the top of the fire chamber, or 50 mm above the top of the highest opening for loading, to the fire chamber floor (ie, below a permanent grate if the grate allows a 25 mm diameter piece of wood to pass through the grate or, if not, to the top of the grate). Firebox dimensions are not necessarily uniform but must account for variations caused by internal baffles, air channels, or other permanent obstructions.

7.1.3

Firebox width and length dimensions are taken to extend to the wall of the appliance above any firebrick or permanent obstruction if the firebrick or obstruction extending the length of the side(s) or back wall extends less than one-third of the usable firebox height. If any firebrick or permanent obstruction extends more than one-third of the usable firebox height, use the width or length dimensions inside the firebrick or permanent obstruction. If a log retainer or grate is a permanent fixture and the manufacturer recommends that no fuel be placed outside the retainer, the area outside the retainer is excluded from the firebox volume calculations. Include areas adjacent to and above a baffle (up to 50 mm above the fuel loading opening) if 100 mm or more horizontal space exists between the edge of the baffle and a vertical obstruction (eg, sidewalls or air channels). Exclude the area above any ash lip if that area is less than 10% of the usable firebox volume or is clearly not readily usable for fuel placement.

7.2 Test Fuel

7.2.1

The test fuel shall be Douglas fir lumber with dimensions as specified in Clause 7.3.1. The average density of the pieces making up a full charge shall be between 380 and 650 kg/m^3.

7.2.2

The fuel shall have a moisture content between 16 and 20% (wet basis) when tested according to ASTM Standard D4442, D4444, or equivalent, and calculated as follows:
$M_c = 100\,(W_w - W_d)/W_w\ \%$

where
M_c = wood moisture content (wet basis) as a percentage
W_w = wet weight of the wood sample, kg
W_d = dry weight of the wood sample, kg
Each piece shall be measured at least three times and both edge and centre piece measurements shall be taken at random.

7.2.3

Kiln-dried lumber shall not be used. Addition of moisture to previously dried wood is not allowed.

7.2.4

The Higher Heating Value (HHV) of a representative sample of the fuel to be used in each appliance test series shall be determined according to ASTM Standard D3286 or D2015.

The average HHV must fall within the range 19 810 ± 1 000 kJ/kg.

Note: ***Sawdust resulting from cutting charge pieces may be used for determining the HHV.***

7.2.5

No pieces with rot, bark, checks exceeding 3 mm in width, pitch-pockets, loose knots, or other defects (tight knots, etc) covering more than 5% of the surface of the fuel pieces shall be used for fuel purposes.

7.2.6

The test fuel shall be within the allowed test room temperature range (18 to 32°C).

7.3 Test Charge

7.3.1

The actual dimensions of each test fuel piece shall conform to the normal actual measurements of nominal 2 x 4 and 4 x 4 lumber, ie, 38 x 89 mm and 89 x 89 mm. Each piece of test fuel (not including spacers) shall be of equal length and shall closely approximate 5/6 of the length of the usable firebox. The fuel piece dimensions shall be determined in relation to the appliance's firebox volume according to guidelines listed below. Shortening pieces uniformly is allowed, to obtain correct weight.

7.3.1.1

If the usable firebox volume is less than or equal to 0.043 m^3, use 2 x 4 lumber.

7.3.1.2

If the usable firebox volume is greater than 0.043 m^3 and less than or equal to 0.085 m^3, use 2 x 4 and 4 x 4 lumber. From 35 to 65% of the weight of the test fuel charge shall be 2 x 4 lumber, and the remainder shall be 4 x 4 lumber.

7.3.1.3

If the usable firebox volume is greater than 0.085 m^3, use 4 x 4 lumber.

7.3.2

Spacers shall be Douglas fir lumber meeting the fuel properties of Clause 7.1. The spacers shall be 130 x 40 x 20 mm (see Figure 4).

7.3.3

Attach the spacers to the test fuel pieces with uncoated, ungalvanized nails or staples. Attachment of spacers to the top of the test fuel piece(s) on top of the test fuel charge is optional.

7.3.4

The test fuel charge density (wet basis) shall be 112 ± 11.2 kg/m^3 of usable firebox volume.

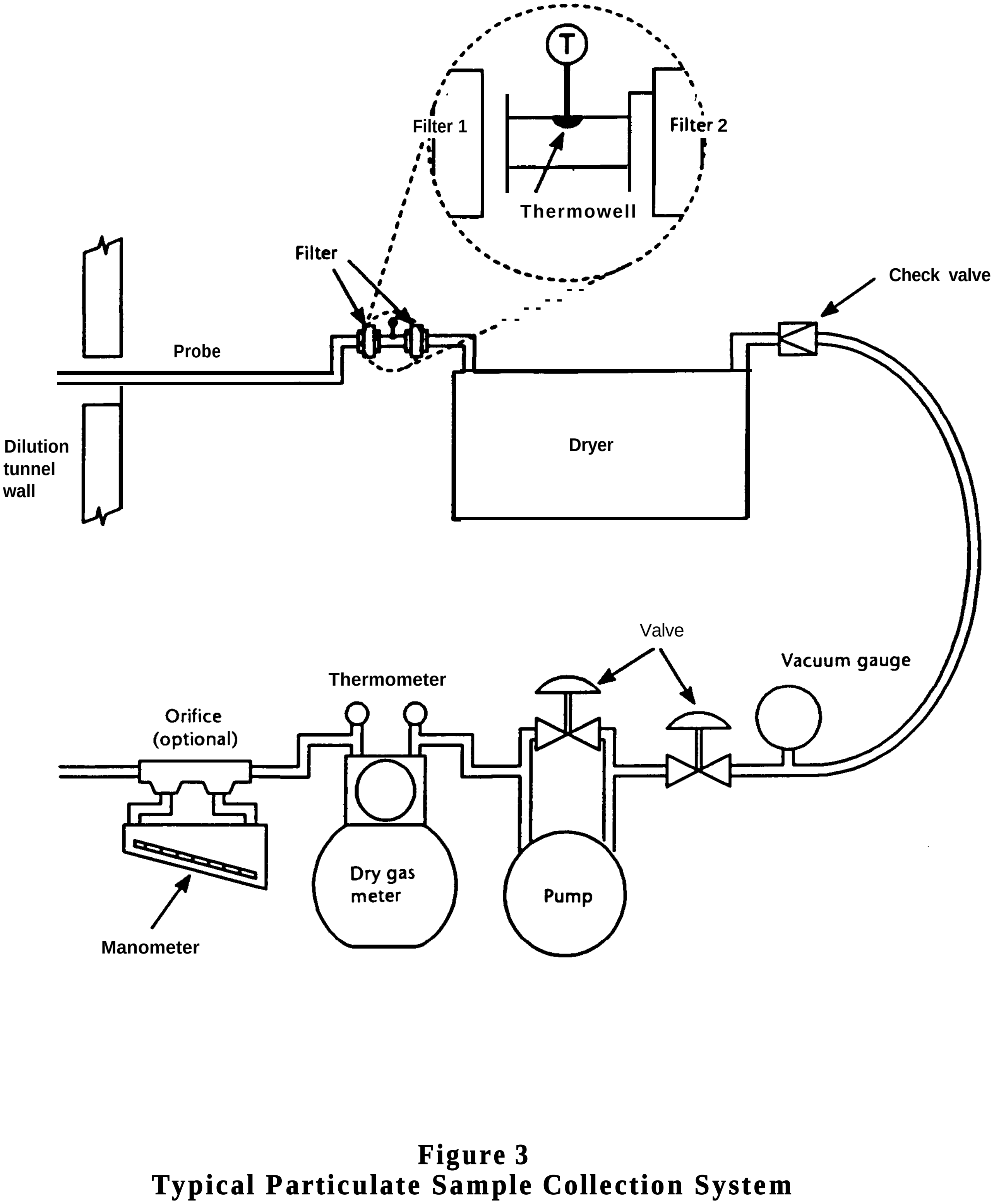


Figure 3
Typical Particulate Sample Collection System

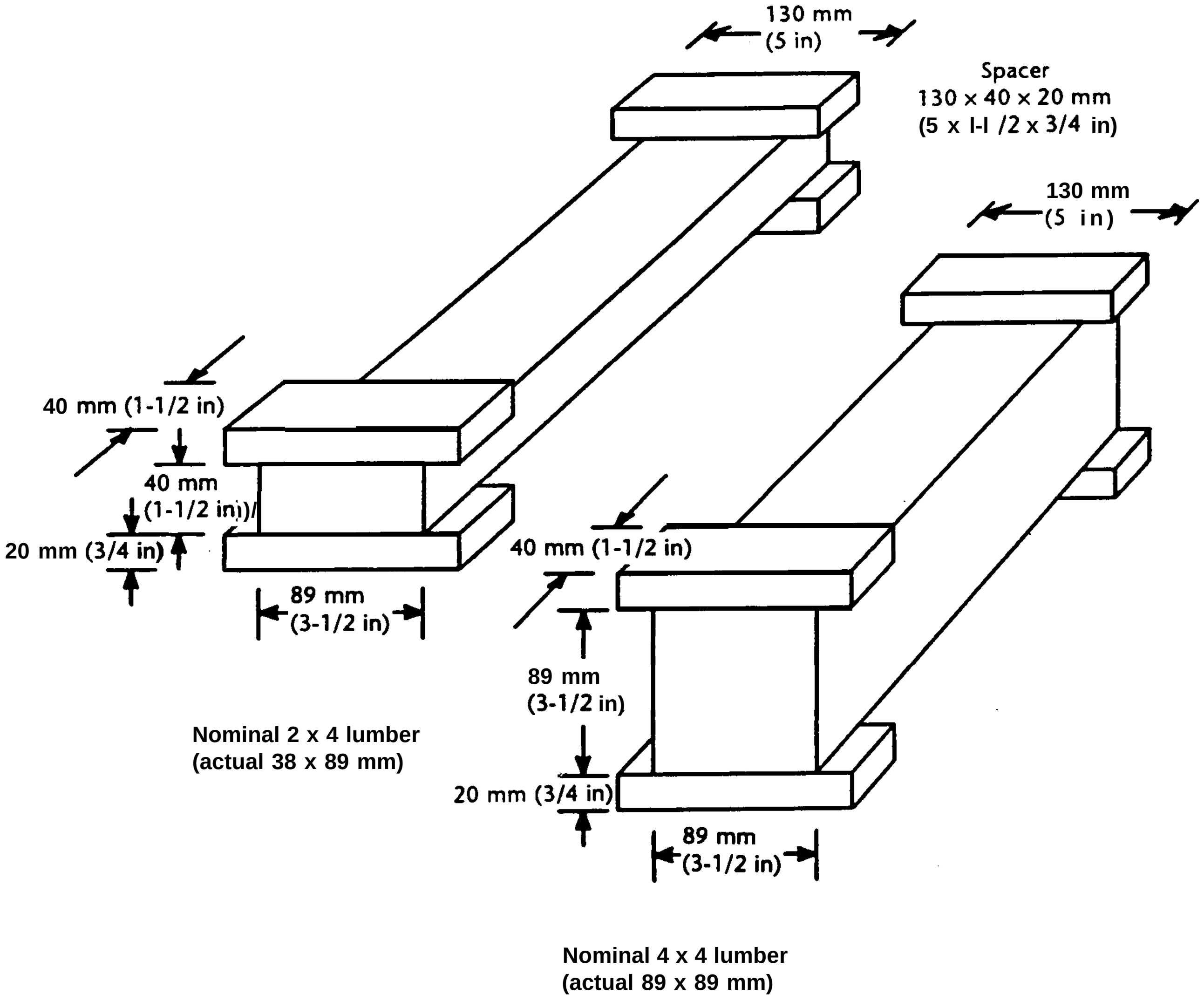


Figure 4
Test Fuel Spacer Dimensions

7.3.5

To avoid stacking difficulties, or to avoid the need to shorten a single fuel piece, all piece lengths shall be adjusted uniformly to remain within the specified loading density. The shape of the test fuel crib shall be geometrically similar to the shape of the firebox without resorting to special angular or round cuts on the individual fuel pieces.

8. Testing Cordwood-Burning Appliances

8.1 General

Appliances shall be tested in accordance with Clauses 5 to 8. For appliances of unusual design or operational characteristics, the test requirements may be suitably modified provided they conform to the intent of this Standard.

8.2 Burn Rates

8.2.1

Appliances which do not have any means of controlling their burn rate shall be tested and emissions reported based on the average of at least three test runs.

8.2.2

For all other appliances, different burn rates as required by Clauses 8.2.3 to 8.2.7 shall be achieved via control settings consistent with the manufacturer's written instructions supplied to the end-user with the unit. If these instructions recommend manual adjustment after refuelling, such adjustments shall be performed during the first 5 min of the burn cycle only.

8.2.3

For appliances having a maximum burn rate at or below 5.3 kg/h, one emission test run is required in each of the following burn-rate categories (rates in kg/h dry basis):

Category 1	Category 2	Category 3	Category 4
<0.80	0.80 to 1.25	1.26 to 1.90	Maximum rate 5.3 or less

8.2.4

For appliances having a maximum burn rate above 5.3 kg/h, one emission test run is required in each of the following burn-rate categories:

Category 1	Category 2	Category 3	Category 4
<15% of maximum	15% to 24% of maximum	24 to 36% of maximum rate	Maximum rate

8.2.5

For Category 4, the appliance shall be operated with the primary air supply inlet controls fully open (or, if thermostatically controlled, the thermostat shall be set at maximum heat output) during the entire test run, or at the maximum burn-rate setting specified by the manufacturer's written instructions.

8.2.6

For burn rates in Categories 1 through 3, the appliance shall be operated with the primary air supply inlet control, or other mechanical control device, set at a predetermined position necessary to obtain the average burn rate required for the category. For appliances using automatically controlled on/off or high/low operation, Categories 1 through 3 shall be obtained by operating the thermostat switch in such a way as to maintain an output with a constant 15 min running average, based on readings taken at 1 min intervals.

8.2.7

If an appliance cannot be operated at a burn rate in Category 1, two test runs shall be conducted with burn rates within Category 2. If an appliance cannot be operated at a burn rate in the Category 2 range, the flue damper shall be used or the air supply otherwise controlled in order to achieve two test runs within Category 2.

Notes:

(1) Evidence that an appliance cannot be operated at a burn rate within Category 1 shall include documentation of two or more attempts to operate the appliance at the upper end of burn-rate Category 1 and fuel combustion has stopped, or results of two or more test runs demonstruting that the bum rates were greater than the maximum Category 1 rate when the air supply controls were adjusted to the lowest possible position or settings. Stopped fuel combustion is evidenced when an elapsed time of 30 min or more has occurred without a measurable (<0.05 kg or 1.0%, whichever is greater) weight change in the test fuel charge.

(2) If on appliance cannot be operated at a burn rate less than the muximum Category 1 rote, at least one test run with an average burn rate in the lower 44% of the Category 2 bum-rate runge shall be conducted. Additionally, if flue dampering must be used to achieve the required bum rutes, results from a test run conducted at burn rates in the lowest 22% of the Category 2 burn-rate runge need not be reported or included in the test run average provided that such results are replaced with results from a test run meeting the criteria above.

8.3 Appliance Operation

8.3.1

The pretest fuel shall meet the same fuel requirements prescribed in Clause 7. The pretest fuel charge shall consist of whole pieces of 2 x 4 and/or 4 x 4 lumber that are no less than 1/3 the length of the test fuel pieces in approximately the same weight ratio as for the test fuel charge. Crumpled newspaper and kindling may be used to help ignite the pretest fuel.

8.3.2

The air inlet supply control(s) may be set at any position that will maintain combustion of the pretest fuel load. At least 1 h before the start of the test run, the air supply controls shall be set at the approximate positions desired for the test run. Adjustment of the air supply controls, fuel addition, and coalbed raking shall be recorded and kept to a minimum but are allowed up to 15 min prior to the start of the test run. Coalbed raking includes stirring coals, breaking burning fuel into smaller pieces, moving fuel pieces from positions of poor combustion, and checking for the condition of uniform charcoalization. Record fuel weight data and wood heater temperature measurements at 10 min intervals during the hour of the pretest ignition period preceding the start of the test run. During the 15 min period prior to the start of the test run the wood heater loading door shall not be open more than a total of 1 min. Coalbed raking is the only adjustment allowed during this period.

Note: One purpose of the pretest ignition period is to achieve uniform charcoalization of the test fuel bed prior to loading the test fuel charge. Uniform charcoalization is a general condition of the test fuel bed

characterized by an absence of large pieces of burning wood in the coalbed and the remaining fuel pieces being brittle enough to be ***broken into smaller charcoal pieces with a metal poker. Manipulations to the fuel bed prior to the start of the test run should be carried out to achieve uniform charcoalization while maintaining the desired burn rate. In addition, some appliances (eg, high mass units) may require extended pretest burn time and fuel additions to reach an initial average surface tempemture sufficient to satisfy Clause 8.7.6. The weight of pretest fuel remaining*** at the ***start of the test run is determined as the difference between the weight of the appliance with the remaining pretest fuel and the tare weight of the cleaned dry appliance with or without dry ash or sand added consistent with the manufacturer's instructions and the owner's manual. The tare weight of the appliance must be determined with the appliance and ash, if added,*** in a dry condition.

8.3.3

When the kindling and pretest fuel have been consumed to leave a fuel weight between 20 and 25% of the weight of the test fuel charge, record the weight of the fuel remaining and start the test run. Record all individual appliance surface temperatures, catalyst temperatures, any initial sampling method measurement values, and begin the particulate emission sampling. Within 1 min following the start of the test run, open the appliance door, load the test fuel charge, and record the test fuel charge weight.

Position the fuel charge so that the spacers are parallel to the floor of the firebox, with the spacer edges abutting each other. If loading difficulties occur, some fuel pieces may be placed on edge. If the usable firebox volume is between 0.043 and 0.085 m^3, alternate the piece sizes in vertical stacking layers to the extent possible. For example, place 2 x 4's on the bottom layer in direct contact with the coalbed and 4 x 4's on the next layer, etc. Position the fuel pieces parallel to each other and parallel to the longest wall of the firebox to the extent possible within the specifications in Clause 7.3 (see Figure 5).

The appliance door may remain open and the air supply controls be adjusted up to 5 min after the start of the test run in order to make adjustments to the test fuel charge and to ensure that ignition of the test fuel charge has occurred. Within the 5 min after the start of the test run, close the appliance door, and catalytic-combustor bypass damper if present, and adjust the air supply controls to the position determined to produce the desired burn rate. No other adjustments to the air supply controls or the test fuel charge are allowed after the first 5 min of the test run. Record the length of time the appliance door remains open, the adjustments to the air supply controls, and other operational adjustments.

8.3.4

Record fuel weight data, individual appliance surface and catalytic combustor temperature measurements, other appliance operational data (eg, draft), test facility temperature, and sampling method data at least every 10 min. (The data sheet shown in Figure 7 or equivalent may be used.)

8.3.5

The test fuel charge may be adjusted (ie, repositioned) once during a test run if more than 60% of the initial test fuel charge weight has been consumed, and if more than 10 min have elapsed with a weight change of less than 0.05 kg or 1% whichever is greater. The time used to make this adjustment shall be less than 15 s.

8.3.6

Heat exchange blowers sold with the appliance shall be operated during the test run following the manufacturer's written instructions. If no manufacturer's written instructions are available, operate the heat exchange blower in the "high" position. Automatically operated blowers shall be operated as designed.

8.3.7

The test run is completed when the remaining weight of the test fuel charge is zero. End the test run when the scale has indicated a test fuel charge weight of 0.00 kg for 30 s. Stop the particulate sampling and record the run time and all final measurement values.

8.3.8

The appliance shall be cleared of ash, nails, and charcoal after no more than four test charges. The procedure described in Clause 8.3.2 shall be repeated prior to further tests. If the manufacturer's instructions recommend a bed of inert material, this inert material shall be replaced to the recommended minimum level.

8.4 Data Collection and Recording

8.4.1

The following information shall be recorded for each test:
(a) times at which any fuel is added;
(b) fuel charge configuration used;
(c) any adjustments to controls made during test preparation and operation; and
(d) final appliance control settings.

8.4.2

Instruments are to be calibrated in accordance with the manufacturer's instructions, and accuracy verified as required. Wherever possible, calibration shall be traceable to National Research Council primary standards, or equivalent,

8.4.3

Calibration and maintenance of equipment and recordkeeping shall be in accordance with Standards Council of Canada requirements.

8.4.4

The ambient pressure and relative humidity shall be determined at least three times during the procedure, including at the beginning, at the midpoint, and at the end of the test. The measurements shall be averaged.

8.4.5

The dry gas meter readings shall be recorded at the beginning and end of each test, and at the end of each sampling time increment. For the purposes of proportional sampling rate determinations, data from calibrated flow rate devices, such as glass rotameters, may be used in lieu of incremental dry gas meter readings. Proportional rate calculation procedures must be revised, but acceptability limits remain the same (see Clause 8.7.7).

8.4.6

The following data shall be recorded at least once every 10 min during the test: time, the sample flow rate Pitot tube signal, tunnel temperature, filter temperature, vent temperature, ambient temperature, wood weight, CO,, 0,, and CO. During the test run, make periodic adjustments to keep the temperature between (or upstream of) the filters at the proper level.

8.4.7

Computations of heat output, efficiency, emissions of various types, and peak flue gas flow rate shall be based on data and samples collected throughout the test cycle.

8.5 Particulate Sampling System

8.5.1 Preparation of Particulate, Sampling System

8.5.1.1

Filters shall be desiccated at 20 ± 5.6°C and ambient pressure to a constant weight, ie, less than 0.5 mg change between two weight measurements at least 2 h apart.

8.5.1.2

The flow measurement sensor, sample probe, and the tubing from it to the filter holder shall be cleaned before each test. The dilution tunnel shall be cleaned before each series.

8.5.1.3

During preparation and assembly of the sample collection system, keep all openings where contamination can occur covered until just prior to assembly or until sampling is about to begin.

8.5.1.4

Using a tweezer or clean disposable surgical gloves, place one labelled (identified) and weighed filter in each of the filter holders. It shall be ensured that each of the filters is properly centered and the gasket properly placed so as to prevent the sample gas stream from circumventing the filter. Check each of the filters for tears after assembly is completed.

8.5.1.5

Mark the probe with heat-resistant tape or by some other method to denote the proper distance into the vent or duct. Set up the sample collection system as in Figure 3.

8.5.2 Leak-Check Procedures

8.5.2.1

The sample collection system shall be checked before the test begins, with the filters in place, to ensure that there are no leaks. Leakage must not exceed 0.57 L/min at a vacuum of 130 mm Hg, when tested in accordance with Environment Canada Method E, Section 5.4.1.2.

8.5.2

A leak-check is mandatory at the conclusion of each test run. The leak-check shall be done in accordance with the procedures described in Environment Canada Method E, Section 5.4.1.2. A vacuum of 130 mm Hg (5 in Hg) or the greatest vacuum measured during the test run, whichever is greater, may be used instead of 380 mm Hg.

8.5.3 Installation of Sample Collection System

8.5.3.1

Position the probe inlet at the vent centroid, and block off the openings around the probe and porthole to prevent unrepresentative dilution of the gas stream. Be careful not to bump the probe into the vent wall when removing or inserting the probe through the porthole; this minimizes the chance of extracting deposited material. During the test run, maintain a sample flow rate proportional to the dilution tunnel flow rate (within 10% of the initial proportionality ratio) and a filter holder temperature of no greater than 32°C. The initial sample flow rate shall be approximately 0.015 m^3/min.

8.5.3.2

Measuring velocity at the centroid of the vent, set the flow to approximately 220 m/min. Using the procedures described in Environment Canada Methods A and B and using a four-point traverse, the actual flow velocity shall be determined.

8.5.3.3

With the dilution tunnel flow at the setting to be used during testing, determine the draft in the appliance vent with no fire in the appliance, the appliance doors closed, and the air supply controls fully open. If the draft exceeds the limit value of Clause 8.6.3, the distance between the top of the chimney and the draft hood shall be adjusted so that the limit value is not exceeded.

8.5.3.4

During the pretest ignition period, visually monitor the chimney exhaust to ensure that, with the appliance door (if so equipped) closed, 100% of the exhaust gas is collected by the dilution tunnel hood. If any exhaust gas is observed to be escaping, the distance between the chimney and the draft hood shall be adjusted to ensure complete capture of the exhaust gas. Repeat Clause 8.5.3.2.

8.5.4 Operation of Sample Collection System

8.5.4.1

Begin sampling at the start of the test run as defined in Clause 8.3.3.

8.5.4.2

The gas flow rate in the dilution tunnel shall be calculated using the reading from the Pitot tube according to Environment Canada Method B, Equation B-2. Moisture content of diluted tunnel gases is assumed to be 4% for making flowrate calculations; the moisture content may be measured directly as in Environment Canada Method D.

Note: ***The dilution tunnel dry gas relative molecular mass may be assumed to be 29 g/gmole.***

8.5.4.3

The flow through the sample collection system shall be calculated, compensating for the temperature, pressure, and relative humidity, in accordance with Environment Canada Method B, Equation B-2, basic principles, and/or the instructions for the flow-measuring device.

8.5.4.4

Sampling shall continue without changing sample collection system or filters until the run is completed.

8.5.4.5

At the end of the test run (see Clause 8.3.7), turn off the coarse adjust valve, remove the probe from the vent, turn off the pump, and record the final dry gas meter reading.

8.5.5 Post-test Operations

8.5.5.1

Following the test cycle, the sampling system and Pitot lines shall be tested to ensure that no leaks have developed.

8.5.5.2

The material collected inside the sample probe, and inside the tubing that extends from the probe to the filter holder, shall be recovered as described in Environment Canada Method E, Section 5.4.2, except that an acetone blank of approximately 50 mL or more shall be used. The samples shall be treated as follows:

(a) Container No. 1. Carefully remove the filter from the primary filter holder and place it in its identified (labelled) petri dish container. Use a pair of tweezers and/or clean disposable surgical gloves to handle the filter. If it is necessary to fold the filter, do so such that the particulate cake is inside the fold. Carefully transfer to the petri dish any particulate matter and/or filter fibres which adhere to the filter holder gasket, by using a dry nylon bristle brush and/or a sharp-edged blade. Seal the container.

(b) Container No. 2. Remove the filter from the second filter holder using the same procedures as described above.

Note: ***The two filters may be placed in the same container for desiccation and weighing. Use the sum of the filter tare weights to determine the sample mass collected.***

(c) Container No. 3. Taking care to see that dust on the outside of the probe or other exterior surfaces does not get into the sample, quantitatively recover particulate matter or any condensate from the probe and filter holders by washing and brushing these components with acetone and placing the wash in a labelled (No. 3) glass container. At least three cycles of brushing and rinsing are necessary.

8.5.5.3

Between sampling runs, the brushes shall be kept clean and protected from contamination.

8.5.5.4

After all acetone washings and particulate matter have been collected in the sample containers, tighten the lids on the sample containers so that the acetone will not leak out when transferred to the laboratory weighing area. Mark the height of the fluid levels to determine whether leakage occurs during transport. Label the containers clearly to identify contents. Requirements for capping and transport of sample containers are not applicable if sample recovery and analysis occur in the same room.

8.5.5.5

Record the data required on a sheet such as the one shown in Figure 8. Use the same analytical balance for determining tare weight and final sample weights. Handle each sample container as follows:

(a) Containers No. 1 and 2. Leave the contents in the sample containers or transfer the filters and loose particulate to tared glass weighting dishes. Desiccate for no more than 36 h before the initial weighing, weigh to a constant weight, and report the results to the nearest 0.1 mg. For purposes of this section, the term “constant weight” means a difference of no more than 0.5 mg or 1% of total sample weight (less tare weight), whichever is greater, between two consecutive weighings, with no less than 2 h between weighings.

(b) Container No. 3. Note the level of liquid in the container, and confirm on the analysis sheet whether leakage occurred during transport. If a noticeable amount of leakage has occurred, void the sample. Determination of sample leakage is not applicable if sample recovery and analysis occur in the same room. Measure the liquid in this container either volumetrically to within 1 mL or gravimetrically to within 0.5 g. Transfer the contents to a tared 250 mL or smaller beaker and evaporate to dryness at ambient temperature and pressure. Desiccate and weigh to a constant weight. Report the results to the nearest 0.1 mg.

(c) “Acetone Blank” Contalner. Measure acetone in this container either volumetrically or gravimetrically. Transfer the acetone to a tared 250 mL or smaller beaker and evaporate to dryness at ambient temperature and pressure. Desiccate and weigh to a constant weight. Report the results to the nearest 0.1 mg.

8.5.5.6

The filters plus any particulate matter and filter fibres from the filter gasket shall be desiccated for not more than 36 h before the initial weight of material is determined.

8.5.5.7

Any filter that is ripped, torn, or otherwise damaged and that was not backed up in series with another undamaged filter shall result in a **nonvalid** test run.

8.6 Operating Limitations

8.6.1

The operating limitations of Clauses 8.6.2 to 8.6.7 shall be met or the test shall be considered invalid.

8.6.2

The collection **hood shall entrain 100% of the flue gases during the entire test.**

8.6.3

The dilution tunnel shall not impose a draft on the appliance greater than 1.25 Pa when tested in accordance with Clause 8.5.3.2.

8.6.4

The particulate filter temperature shall not exceed 32°C during the run.

8.6.5

The particulate sample flow velocity during the test run shall be within 10% of the dilution tunnel flow velocity.

Note: *An initial sample flow of* 0.015 m^3/min *should normally be used,*

8.6.6

The average of the five appliance surface temperature measurements at the start of the test run and the average at the test run completion shall be within 70°C.

8.6.7

The proportional rate variation PR, as determined in Clause 10.2, shall satisfy the condition $80 \leq PR \leq 120$ for all values and $90 \leq PR \leq 110$ for at least 90% of values.

9. Testing Particulate-Burning Appliances

9.1 General

Testing procedures for particulate-burning appliances are based on the procedures for cordwood-fired appliances with the following differences.

9.2 Fuel

For pellet-burning appliances, the test fuel shall be wood pellets with a moisture content no greater than 8% wet basis determined using ASTM Standard D4442. For particulate-burning appliances designed for other fuels (such as wood chips or corn), the test fuels shall be designated by the manufacturer. In both these cases, the test fuels shall be indicated on the appliance label.

9.3 Fuel Charge

The test fuel charge size shall be in accordance with the manufacturer's written instructions for maintaining the desired burn rate, irrespective of **firebox** volume.

9.4 Appliance Operation

9.4.1

The fire shall be started in the unit in accordance with the manufacturer's written instructions, with the controls adjusted to achieve the desired burn rate. Operate the appliance at the desired burn rate for at least 1 h before the start of the test run.

9.4.2

When the appliance has operated for at least 1 h at the desired burn rate, add fuel to the supply hopper as necessary to complete the test run, determine the weight of the fuel in the supply hopper, and start the test run. Add no additional fuel to the hopper during the test run. Make no manual adjustments to the appliance air supply or wood supply rate during the test run.

9.4.3

Continue appliance testing for at least 2 h. At the end of the test period stop the particulate sampling and determine the final fuel weight, the run time, and all final measurement values.

9.4.4

Determine the burn rate using the difference between the initial and final fuel weights, and the burn time.

10. Results

10.1 Nomenclature

BR_i = Dry fuel burn rate for each test run i, kg/h

CO = Percentage by volume of carbon monoxide in the vent gas

CO_2 = Percentage by volume of carbon dioxide in the vent gas

c_s = Concentration of particulate matter in vent gas, dry basis, corrected to standard conditions, g/sm^3 dry (g/dry standard cubic metre)

D_m = Average pressure differential across the orifice meter, if used, mm H_2O

E_c = Average carbon monoxide emission rate, g/MJ

E_i = Particulate emission rate for test run i, g/h or g/MJ

E_w = Average particulate emission rate, g/h or g/MJ

K_i = Test run weighting factor = $P_{(i+1)} - P_{(i-1)}$

K_1 = 0.3858 deg K/mm Hg

L_a = Maximum acceptable leakage rate for either a pretest or post-test leak check, equal to 0.00057 m^3/min or 4% of the average sampling rate, whichever is less

L_p = Leakage rate observed during the post-test leak check, m^3/min

m_a = Mass of residue of acetone blank after evaporation, mg

m_{aw} = Mass of residue from acetone wash after evaporation, mg

M_c = Average moisture in test fuel (per cent wet basis)

m_n = Total amount of particulate matter collected, mg

n = Total number of test runs

P_{bar} = Barometric pressure at the sampling site, mm Hg

P_i = Probability for burn rate during test run, i, obtained from Table 1

PR = Percentage of proportional sampling rate

P_{std} = Standard absolute pressure, 760 mm Hg

Q_{sd} = Average gas flow rate in dilution tunnel as determined using Environment Canada Standard Reference Methods, Method B, sm^3 dry/h

T_m = Absolute average dry gas meter temperature, deg K

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

T_r = Total time of test run (min)

T_s = Absolute average gas temperature in the dilution tunnel, deg K

T_{si} = Absolute average gas temperature in the dilution tunnel during each 10 min interval, i, of the test run, deg K

T_{std} = Standard absolute temperature, 293 deg K

T_t = Total sampling time, min

V_a = Volume of acetone blank, mL

V_{aw} = Volume of acetone used in wash, mL

V_m = Volume of gas sample as measured by dry gas meter, m^3 dry

V_{mi} = Volume of gas sample as measured by dry gas meter during each 10 min interval, i, of the test run, m^3 dry

$V_{m(std)}$ = Volume of gas sample measured by the dry gas meter, corrected to standard conditions, sm^3 dry

v_s = Average gas velocity in dilution tunnel, m/s. The dilution tunnel dry gas molecular weight may be assumed to be 29 g/gmole

v_{si} = Average gas velocity in dilution tunnel during each 10 min interval, i, of the test run, m/s

W_{wd} = Total mass of wood burnt during the test run, including weight of moisture in wood, kg
w_i = Change in wet wood weight over any interval, i, of a test run
Y = Dry gas meter calibration factor

10.2 Proportional Rate Variation

The proportional rate variation PR for each 10 min interval, i, of the test run is

$$PR = \frac{T_t (V_{mi} \times v_s \times T_m \times T_{si})}{10 (V_m \times v_{si} \times T_s \times T_{mi})} \times 100 \qquad (10\text{-}1)$$

(Note that alternate calculation procedures for proportional rate variation may be used if test instrumentation used generates other flow rate data. The proportional rate variations shall be calculated for each 10 min interval by comparing the vent to **nozzle velocity ratio** for each 10 min interval to the average vent to nozzle velocity ratio for the test run. Proportional rate variation may be calculated **for intervals shorter than 10 min with appropriate revisions to Equation 1 O-l .)**

If 80 ≤ PR ≤ 120 for all values and 90 ≤ PR ≤ 110 for at least 90% of PR values then the results are acceptable. If the PR values for the test run are unacceptable, the results must be kept but shall not be included in calculating the weighted average emission rates or in meeting minimum number of run criteria.

10.3 Conversion to Standard Conditions

Conversion of sample volume to standard conditions, **20°C,** 760 mm Hg

0

$$V_{m(std)} = V_m Y \left(\frac{T_{std}}{T_m}\right) \left(\frac{P_{bar} + (D_m/13.6)}{P_{std}}\right) = K_1 V_m Y \left(\frac{P_{bar} + (D_m/13.6)}{T_m}\right) \qquad (1\ 0\text{-}2)$$

Note: If L_p exceeds L_a, Equation 1 O-2 must be modified as follows:
Replace V_m in Equation 1 O-4 with the expression $V_m - (L_p - L_a) \times T_t$.

10.4 Solvent Wash Blank

The mass of residue obtained after evaporation of the acetone solvent wash may be obtained as **follows:**

$$m_{aw} = \frac{m_a \times V_{aw}}{V_a} \qquad (10\text{-}3)$$

10.5 Total Particulate Catch

The total particulate catch is the sum of the weights obtained from Containers 1, 2, and 3 less the acetone blank.

10.6 Particulate Concentration

The particulate concentration is

$$c_s = 0.001 \times m_n / V_{m(std)} \qquad (10\text{-}4)$$

10.7 Burn Rate

The burn rate BR, for each test run i is

$$BR_i = \left(\frac{60 \times W_{wd}}{T_r}\right) \times \left(\frac{100 - F_m}{100}\right) \qquad (1\ 0\text{-}5)$$

10.8 Particulate Emission Rate

The particulate emission rate for each test run i is

$$E_i = c_s \times Q_{sd} \text{ (g/h) or } E_i = \frac{0.05048 \times c_s \times Q_{sd}}{BR_i} \text{ (g/MJ)} \qquad (10\text{-}6)$$

10.9 Average Particulate Emission Rate

10.9.1

For appliances with a maximum burn rate less than 5.3 kg/h, the average particulate emission rate E_w shall be the weighted average determined from:

$$E_w = \frac{\sum_{i=1}^{tot} (K_i E_i)}{\sum_{i=1}^{tot} (K_i)} \qquad (10\text{-}7)$$

Note: P_0 always equals 0, P_{n+1} always equals 1, P_1 corresponds to the probability of the lowest recorded burn rate, P_2 corresponds to the probability of the next lowest burn rate, etc. See Appendix A for an example.

10.9.2

For appliances with a maximum burn rate equal to or greater than 5.3 kg/h, the average particulate emission rate E_w shall be the numerical average of the particulate emissions from each burn rate range. If the results from more than one test are used in a given burn rate range, the average result for this range shall be determined in accordance with Clause 12 before the overall average is determined.

10.10 Efficiency and Carbon Monoxide

10.10.1 General

Efficiency may be determined using the procedure described below (see Appendix 8 for example) or using the alternative procedure described in Appendix C.

10.10.2 Initial Values

The initial values shall be determined using the following equations:

$x = 100(Wt_m - Wt)/Wt_m$

$Wt_{do} = 0.01 \times Wt, \times (100 - M_{cwb})$

$Wt_{dn} = Wt(1 - 0.01 \times M_{cwb} \times e^{-0.0129x})$

$Y = 100(Wt_{do} - Wt_{dn})/Wt_{do}$

$R = 3.64 - 0.11864x + 0.001\,536x^2 - 0.0000073x^3$

$M_{wb} = M_{cwb} \times R$

$M_d = 100 \times M_w/(100 - M_w)$

$CA = C_o(0.5886 + 0.01344{\sim} - 0.0003341y^2 + 0.00000341\,2y^3)$

$HY = H_o(1.293 + 0.004875{\sim} - 0.000161y^2)$

$OX = 100 - (CA + HY)$

$CV = CV_o\,(0.6126 + 0.009541y - 0.0001761\,y^2 + 0.000001\,9894y^3)$

where

Wt_m = initial wet weight of the fuel charge

Wt = weight of the wet fuel charge now

Wt_{do} = initial dry weight of the fuel charge
M_{cwb} = initial moisture content of the fuel charge (wet basis; use 18%)
Wt_{dn} = dry weight of the fuel charge now
R = that portion of the original wood moisture content which is being evaporated at the moment of sampling
M_{wb} = moisture content of the fuel burning (% wet basis)
M_{db} = moisture content of the fuel burning (% dry basis)
CA = percentage of carbon in the dry fuel burning
HY = percentage of hydrogen in the dry fuel burning
ox = percentage of oxygen in the dry fuel burning
CV = dry calorific value (kJ/kg) of the fuel burning
Ccl = percentage of carbon in the fuel at the beginning of the burn cycle (use 48.73)
H_o = percentage of hydrogen in the fuel at the beginning of the burn cycle (use 6.87)
CV_o = dry calorific value of the fuel at the beginning of the burn cycle (use 19 810 kJ/kg)
x = percentage of the total fuel plus moisture mass consumed
Y = percentage of the dry fuel mass consumed

Note: *The fuel is **assumed** to **contain** 0.5% **ash.***

10.10.3 Combustion Equation

Results calculated shall be based on the following chemical equation modelling the wood combustion:

$$wC_aH_bO_c + uO_2 + 3.77uN_2 = dCO_2 + eCO + gO_2 + hN_2 + jH_2O + kCH_4$$

where
w = moles of dry fuel per 100 moles of dry flue gas
a = fraction of carbon atoms in the fuel
b = fraction of hydrogen atoms in the fuel
c = fraction of oxygen atoms in the fuel
u = moles of oxygen entering per 100 moles of dry flue gas
d = moles of CO2 per 100 moles of dry flue gas
e = moles of CO per 100 moles of dry flue gas
g = moles of O_2 per 100 moles of dry flue gas
h = moles of N_2 per 100 moles of dry flue gas
j = moles of H20 per 100 moles of dry flue gas
k = moles of CH_4 per 100 moles of dry flue gas

10.10.4 Fuel Constituents Ratio

Values for a, b, and c shall be determined from the equations
a = CA/12
b = HY/1
c = OX/16

10.10.5 Mass Balance

Balancing the masses of elemental constituents present, the following equations are obtained:
Carbon balance: aw = d + e + k
Hydrogen balance: bw = 2j + 4k
Oxygen balance: cw + 2u = 2d + e + 2g + j
Nitrogen balance: 3.77u = h
Sum of dry products: d + e + g + h = 100

Solving these equations yields values for the unknowns w, u, h, j, and k, as follows:

$h = 100 - d - e - g$

$u = h/3.77$

$w = (8d + 4g + 6e - 4u)/(4a - b + 2c)$

$k = wa - d - e$

$j = (Bw - 4k)/2$

This allows determination of the weight of dry wood input per 100 moles of dry flue gas, and the moles of flue products per unit weight of dry wood input.

10.10.6 Moisture in Fuel

Additional moisture is present as water in the fuel charge. The weight of water per unit weight of fuel is calculated using the equation in Clause 10.10.2 for M_{wb}. Since this weight is unchanged by the reaction, it is also present in the flue gas and shall be added to the j term to obtain the total water in the flue gases.

10.10.7 Heat Content

Given the weight of fuel consumed over any time interval, the number of litres of product can be calculated using the values found above. If the litres of product are determined for the fuel input over the interval, then the instantaneous vent losses can be calculated as:

$li = \sum$ [litres of product x (enthalpy of product at vent temperature – enthalpy of product at ambient temperature)]

Enthalpies in joules/mole shall be calculated using the following equations:

$$\text{LOSS rate} = \sum_{i=I}^{6} \dot{n}_i (h_{i,Ts} - h_{i,TR}) + \dot{n}_{CO}\ 282\,993 + \dot{n}_{CH_4(\ell)}\ 890\,156 + \dot{n}_{H_2O}\ 43\,969$$

where

$h_{i,Ts}$ = enthalpy of species i at vent temperature

$h_{i,TR}$ = enthalpy of species i at room temperature

$\dot{n}_i$ = molar flow rate of species i

$h_{CO} = 22359T^{0.25} - 4015.4T^{0.5} + 69.145T - 0.012733T^{1.75}$

$h_{CO,} = -3.7357T + 2.0353T^{1.5} - 0.020517T^2 + (8.0660 \times 10^{-7} \times T^3)$

$h_{H_2O} = 143.05T - 46.432T^{1.25} + 5.5167T^{1.5} - 0.018495T^2$

$h_{O_2} = (-236.88 \times 10' \times T^{-1}) + (3.5714 \times 10^5 \times T^{-0.5}) + 37.432T + (8.0408 \times 10^{-6} \times T^{2.5})$

$h_{N_2} = (-1072.7 \times 10^4 \times T^{-1}) + (1025.58 \times 10^3 \times T^{-0.5}) + 39.060T + (410.2 \times 10^6 \times T^{-2})$

$h_{CH,} = 6477.6T^{0.5} - 672.87T + 111.25T^{1.25} - 0.4495T^{1.75}$

Ts = the vent temperature in degrees kelvin (degrees Celsius + 273.15)

TR = the ambient temperature in degrees kelvin (degrees Celsius + 273.15)

Total losses are thus

$L = \sum (li \times dw)/W$

where

li = the sum of the enthalpies of the flue products over any portion of the run

dw = the dry weight interval between measurement of flue products

W = the total dry weight loss during the sampling period

Total input I = the total weight of fuel burnt during the test period times the calorific value of fuel per unit weight

Therefore, the heat output of the appliance is I – L.

10.10.8 Efficiency

The efficiency of the appliance shall be calculated as

$n_i = 100 (I - L)/I$

where

n_i = the efficiency, %, for test run i

I = total energy input, MJ

L = total vent losses, MJ

10.11 **Average Vent Temperature**

The average vent temperature for the burn is

$$T = \sum_{i=1}^{wt} t_i \Delta w_i / W$$

where

T = the average vent temperature

t_i = the vent temperature for interval i

Δw_i = the dry fuel weight loss for interval i

W = the total dry fuel weight loss during the sampling period

10.12 CO Emissions

The CO emissions in g/MJ shall be determined from

$$W_{CO} = \left(\sum_{i=1}^{wt} n_{COi} \text{ X } 28 \text{ x } \Delta w_i \right) + I$$

where

W_{CO} = the total CO emission over the burn

n_{COi} = the moles of CO over weight interval i

w_i = the dry fuel weight loss in interval i

I = total fuel energy input during the test, MJ (equals Wt,, x 19.81)

10.13 **Average Efficiency**

10.13.1

Only efficiency values from test runs satisfying the requirements of Clause 11 shall be used in determining the average efficiency.

10.13.2

for appliances with a maximum burn rate less than 5.3 kg/h, the average efficiency n shall be the weighted average determined from:

$$n = \frac{\sum_{i=1}^{tot} (K_i n_i)}{\sum_{i=1}^{tot} (K_i)}$$

where

n = the overall average efficiency

n_i = the average efficiency for test run i

K, and P, are as defined in Clause 10.1

Note: Po ***always equals 0,*** $P_n + 1$ ***always equals 1,*** P_1 ***corresponds to the probability of the lowest recorded***

burn rote, P2 corresponds to the probability of the next lowest burn rate, etc. See Appendix A for an example.

10.13.3

For appliances with a maximum burn rate equal to or greater than 5.3 kg/h, the average efficiency n shall be the numerical average of the efficiency from each burn rate range. If the results from more than one test are used in a given burn rate range, the average result for this range shall be determined in accordance with Clause 12 before the overall average is determined.

11. Vent Temperature

11.1

Unless the appliance and venting system employ materials and design criteria to prevent corrosion, accumulation of condensate, and an unacceptably low draft,
(a) the minimum labelled heat output rate; and
(b) the efficiency of any run to be used in calculating the weighted average efficiency
shall be that resulting in an average vent temperature (as defined in Clause 10.11) over the test cycle of not less than 115°C. Appliances intended for lower average temperatures shall be subject to such tests as the testing agency deems appropriate to verify suitability at lower temperatures.

12. Multiple Results Within One Burn-Rate Category

12.1

If more than one test run is conducted within a specified burn-rate category, the results from at least two-thirds of the test runs in that category shall be used in calculating the average values. Measurement data and results of all test runs shall be retained regardless of which values are used in calculating the weighted average.

13. Marking

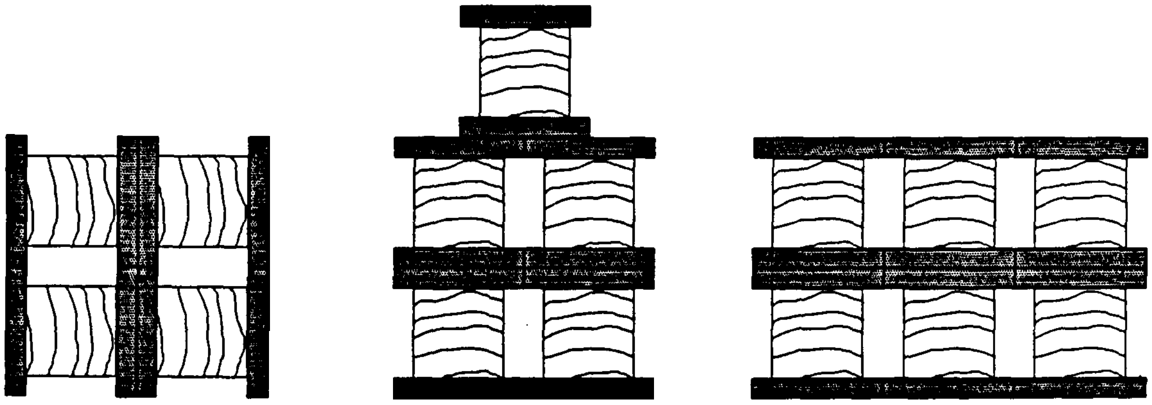
13.1

Each appliance shall bear a permanent marking with the following information:
(a) the average particulate emission rate in g/h;
(b) the average efficiency of the appliance as a percentage;
(c) the minimum heat output rate from a test used in determining the average emission rate; and
(d) the maximum heat output rate from a test used in determining the average emission rate.

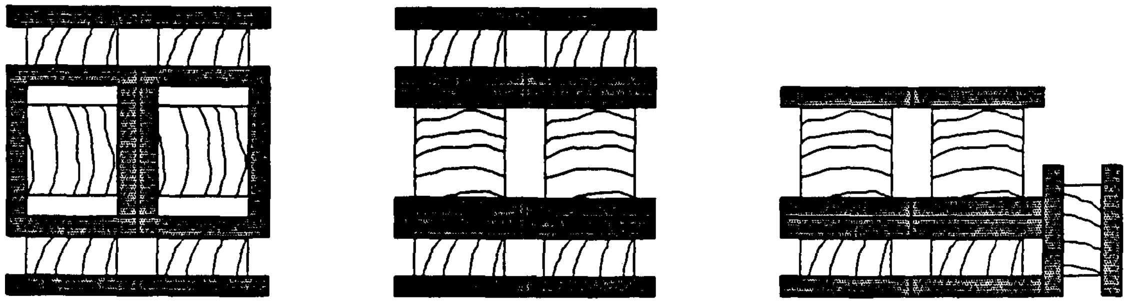
13.2

The lettering on the label which provides the above information shall be a minimum of 2 mm in height.

2 x 4
(38 x 89 mm)



4 x 4
(89 x 89 mm)



2 x 4 and 4 x 4
(38 x 89 mm and 89 x 89 mm)

Figure 5
Test Fuel Crib Arrangements

Appliance Identification

Appliance Manufacturer ______

Address ______

Agent and Phone Number ______

Name and Model Number ______

Weight ______

Serial Number ______

Design: Catalytic ______ Noncatalytic ______

Insert ______ Freestanding ______

Appliance Description: ***(Attach figure showing air supplies and firebox configuration, and photos of front, side and rear).***

Materials of Construction ______

Air Introduction System ______

Combustion Control Mechanisms ______

Internal Baffles ______

Other Features ______

Catalytic Combustor Specifications

Manufacturer ______

Serial Number ______

Age ______(hours)

Dimensions ______(mm)

Test Fuel Information (for **each** test result)

Weight of Test Charge ______(kg)

Number of 2 x 4's ______

Number of 4 x 4's ______

Length of test pieces ______(cm)

Fuel Grade (Certification) ______

Fuel Moisture Content ______**(%)**

Firebox Dimensions (m)

Volume ______

Length ______

Weight ______

Height ______

Adjustment (Description) ______

Diagram or Photo of Test Fuel Crib

Figure 6
Appliance and Test Fuel Information

Date ______________________ Sheet ______ of ______

Operator ____________________

Sampling Method ____________

Appliance Information

Manufacturer ____________________

Model ____________________

Primary Air Setting ____________________

Secondary Air Setting ____________________

Thermostat Setting ____________________

Other Settings ____________________

Test Run Information

Test Run No. ____________________

Burn Rate ____________________

Room Temperature before/after _ / _

Barometric Pressure before/after _ / _

Relative Humidity before/after _ / _

Room Air Velocity before/after _ / _

Surface Temp. Average Pretest end ____

Test run time (min)	Test fuel scale reading (kg)	Surface temperature	Catalytic combustor temperature		Flue draft (Pa)
			Inlet (°C)	Outlet (“C)	
(Pretest Period)					
(Test Run Start)					

Figure 7
Test Run Appliance Operation Data Sheet

Stove ______

Date ______

Run No. ______

Filter Nos. ______

Liquid Lost During Transport, mL ______

Acetone Blank Volume, mL ______

Acetone Wash Volume, mL ______

Acetone Blank Concentration, mg/mg ______

Acetone Wash Blank, mg ______

	Weight of Particulate Collected, mg		
Container number	**Final weight**	**Tare weight**	**Weight gain**
1			
2			
3			
Total			
Less acetone blank			
Weight of particulate matter			

Vent Moisture Measurement Data (Optional)

	Volume of Liquid Water Collected	
	Impinger volume, mL	**Silica gel weight, g**
Final		
Initial		
Liquid collected		*
Total volume collected		______ mL

Convert weight of water to volume by dividing total weight increase by density of water (1 g/mL).

$$\frac{\text{Increase, g}}{(1\ \text{g/mL})} = \text{Volume water, mL}$$

Figure 8
Analysis Data Sheet

Table 1
Burn Rate Weighted Probabilities for Calculating Weighted Average Emission Rates

Burn rate, kg/h-dry	Cumulative probability, P	Burn rate, kg/h-dry	Cumulative probability, P	Burn rate, kg/h-dry	Cumulative probability, P
0.00	0.000	2.00	0.912	4.00	0.994
0.05	0.002	2.05	0.920	4.05	0.995
0.10	0.007	2.10	0.925	4.10	0.995
0.15	0.012	2.15	0.932	4.15	0.995
0.20	0.016	2.20	0.936	4.20	0.995
0.25	0.021	2.25	0.940	4.25	0.995
0.30	0.028	2.30	0.945	4.30	0.996
0.35	0.033	2.35	0.951	4.35	0.996
0.40	0.041	2.40	0.956	4.40	0.996
0.45	0.054	2.45	0.959	4.45	0.996
0.50	0.065	2.50	0.964	4.50	0.996
0.55	0.086	2.55	0.968	4.55	0.996
0.60	0.100	2.60	0.972	4.60	0.996
0.65	0.121	2.65	0.975	4.65	0.996
0.70	0.150	2.70	0.977	4.70	0.996
0.75	0.185	2.75	0.979	4.75	0.997
0.80	0.220	2.80	0.980	4.80	0.997
0.85	0.254	2.85	0.981	4.85	0.997
0.90	0.300	2.90	0.982	4.90	0.997
0.95	0.328	2.95	0.984	4.95	0.997
1.00	0.380	3.00	0.984	>5.00	1.000
1.05	0.407	3.05	0.985		
1.10	0.460	3.10	0.986		
1.15	0.490	3.15	0.987		
1.20	0.550	3.20	0.987		
1.25	0.572	3.25	0.988		
1.30	0.620	3.30	0.988		
1.35	0.654	3.35	0.989		
1.40	0.695	3.40	0.989		
1.45	0.722	3.45	0.989		
1.50	0.750	3.50	0.990		
1.55	0.779	3.55	0.991		
1.60	0.800	3.60	0.991		
1.65	0.825	3.65	0.992		
1.70	0.840	3.70	0.992		
1.75	0.857	3.75	0.992		
1.80	0.875	3.80	0.993		
1.85	0.882	3.85	0.994		
1.90	0.895	3.90	0.994		
1.95	0.906	3.95	0.994		

Appendix A
Calculation of Weighted Average Emission Rate — An Example (see Clauses 10.9.1 and 10.13.1 for definition of parameters)

Burn rate category	**Test** number	**Burn rate, dry-kg/h**	Emissions, **g/h**
1	1	0.65	5.0
2*	2	0.85	6.7
2	3	0.90	4.7
2	4	1.00	5.3
3	5	1.45	3.8
4	**6**	2.00	5.1

*As permitted in Clause 12, this test run may be omitted from the calculation of the weighted average emission rate because three runs were conducted for this burn-rate category.

Test number	**Burn rate**	P_i	E_i, **g/h**	K_i
1	0.65	0.121	5.0	0.300
2	0.90	0.300	4.7	0.259
3	1.00	0.380	5.3	0.422
4	1.45	0.722	3.8	0.532
5	2.00	0.912	5.1	0.278

$K_1 = P_2 - P_0 = 0.300 - 0 = 0.300$

$K_2 = P_3 - P_1 = 0.380 - 0.121 = 0.259$

$K_3 = P_4 - P_2 = 0.722 - 0.300 = 0.422$

$K_4 = P_5 - P_3 = 0.912 - 0.380 = 0.532$

$K_5 = P_6 - P_1 = 1 - 0.722 = 0.278$

$$\sum_{i=1}^{n} K_i = 0.300 + 0.259 + 0.422 + 0.532 + 0.278$$

$$\sum_{i=1}^{n} = 1.791$$

$$E_w = \frac{\sum_{i=1}^{n} (K_i E_i)}{\sum_{i=1}^{n} K_i}$$

$$E_w = \frac{(0.3)\ (5.0) + (0.259)\ (4.7) + (0.422)\ (5.3) + (0.532)\ (3.8) + (0.278)\ (5.1)}{1.791}$$

$E_w = 4.69$ g/h

Appendix B
Sample Calculation of Efficiency and Carbon Monoxide Emissions

Note: *This Appendix* is *not a* mandatory *part of* this Standard.

A stove was charged with 10.00 kg of 18% moisture (wet basis) fuel for a test run. The following data were obtained during the run:

Time, h	Temperature, °C		Wood weight, kg	% flue gas component		
	Vent	Ambient		CO_2	O_2	CO
0.26	300	18	9.75	15.30	2.92	0.71
0.36	400	18	9.25	17.48	3.04	1.72
0.44	500	18	8.75	15.98	2.79	3.41
0.53	400	18	8.25	12.60	6.83	3.86
0.63	300	18	7.75	9.68	6.50	7.96
0.74	200	18	7.25	13.43	7.03	0.00
0.88	200	18	6.75	11.09	9.12	1.27
1.09	200	18	6.25	10.21	9.03	2.65
1.25	200	18	5.75	7.88	12.10	3.09
1.39	200	18	5.25	5.70	11.84	6.38
1.54	200	18	4.75	10.46	10.48	0.00
1.72	200	18	4.25	8.57	12.19	1.08
1.90	200	18	3.75	7.93	12.03	2.14
2.09	200	18	3.25	6.30	14.22	2.37
2.43	200	18	2.75	4.94	13.80	4.56
2.66	100	18	2.25	4.24	16.75	0.00
2.87	100	18	1.75	3.61	17.28	0.35
3.10	100	18	1.25	3.40	17.21	0.64
3.54	50	18	0.75	2.95	17.78	0.68
3.87	50	18	0.25	2.59	17.62	1.23

The weight had returned to its original value after 4.00 h.

The initial wet weight is 10.00 kg.

The initial dry weight is given by

wet weight x (1 – 0.01 x initial % moisture content)

= 10.00 (1 – 0.01 x 18.0)

= 8.20 kg

A sample of calculations for the time 0.53 is shown below. The results shown were obtained from computer calculation. If the operations shown here are performed, slight round-off errors may be present.

Wet fuel weight is 8.25 kg.

% wet fuel burnt = 100 (initial weight – weight now)/initial weight

= 100 (10.00 – 8.25)/1 0.00

= 17.50%

The dry fuel weight is given by

wet weight (1 – 0.01 x initial % moisture x $e^{-0.0129 \times \% \text{ wet fuel burnt}}$)

= 8.25 (1 – 0.01 x 18 x $e^{-0.0129 \times 17.5}$)

$= 7.065$ kg

The % dry weight burnt is given by

100 x (initial dry weight − dry weight now)/ initial dry weight

$= 100(8.2 - 7.065)/8.2$

$= 13.84\%$

Next determine the dry weight change interval over which the values to be calculated will apply. The interval starts at the end of the preceding interval, which was determined during the analysis of the preceding data line to be 7.237 kg. The end of the interval is defined as the half-way point by dry weight change between the current set of readings and the next set.

The next dry fuel weight is at time 0.63, when the wet fuel weight is 7.75 kg, or 22.5% wet fuel burnt. The dry weight is given by

$7.75\,(1 - 0.01 \times 18e^{-0.0129 \times 22.5}) = 6.706$ kg

Thus, the end of the interval is at $(6.706 + 7.065)/2 = 6.886$ kg. The amount of dry fuel burnt during the interval is $(7.237 - 6.886)$, which is 0.351. Note that for the first line of data, the beginning of the weight interval is the initial dry weight of 8.20 kg, while for the last line of data, the end of the interval is at a dry weight of 0 kg.

The initial ultimate analysis and calorific value of the fuel are taken to be

Carbon $C_o = 48.73\%$
Hydrogen $H_o = 6.87\%$
Oxygen $O_o = 43.90\%$
Ash $A_o = 0.50\%$
Calorific value $CV_o = 19810$ kJ/kg

For the readings at time 0.53, the ultimate analysis of the fuel is found from

% Carbon $= C_o\,(0.5886 + 1.344 \times 10^{-2}y - 3.341 \times 10^{-4}y^2 + 3.412 \times 10^{-6}y^3)$
$= 35.07\%$

% Hydrogen $= H_o\,(1.293 + 4.875 \times 10^{-3}y - 1.61 \times 10^{-4}y^2)$
$= 9.13\%$

% Oxygen = 99.5 − % Carbon − % Hydrogen
$= 55.30\%$

The calorific value is given by

$CV = CV_o\,(0.6126 + 9.541 \times 10^{-3}y - 1.761 \times 10^{-4}y^2 + 1.9894 \times 10^{-6}y^3)$
$= 14188$ kJ/kg

where

y = % dry fuel mass consumed (13.84)

The moisture content of the fuel burning over this interval is given by

$M_w = 0.01 \times$ initial % moisture $(364 - 11.864x + 0.1536x^2 - 0.00073x^3)$

where

x = % wet fuel mass consumed (17.50)

The basic equation used to solve for volumes of inputs and products is

$wC_aH_bO_c + uO_2 + 3.77uN_2 = dCO_2 + eCO + gO_2 + hN_2 + jH_2O + kCH_4$

where

a = % Carbon/12 = 35.07/12 = 2.92
b = % Hydrogen/1 = 9.13
c = % Oxygen/16 = 55.30/16 = 3.46

If all values are expressed in moles per 100 moles of dry flue gas, then the values of d, e, and g are known from our readings. The equations used to solve for the unknowns are

$h = 100 - d - e - g$

$u = h/3.77$

w = (8d + 4g + 6e – 4u)/(4a – b + 2c)
k = w a - d - e
j = (bw – 4k)/2

where
h = 100 – 12.60 – 3.86 – 6.83 = 76.71
u = h/3.77 = 20.35
w = (8 x 12.60 + 4 x 6.83 + 6 x 3.86 – 4 x 20.35)/(4 x 2.92 – 9.13 + 2 x 3.46)
= 7.38
k = 7.38 x 2.92 – 12.60 – 3.86 = 5.11
j = (9.13 x 7.38 – 4 x 5.11)/2 = 23.49

Now the number of moles of dry wood per 100 moles of dry flue gas is known. The number of kilograms of wood per 100 moles of dry flue gas is needed. This is given by

N_k = 0.001 x w(12a + b+ 16c)
= 0.7345 kg/l 00 moles of dry flue gas

Then the number of moles of each input and product per kg of dry wood can be calculated. For instance:

moles of CO_2/kg of dry wood = d/N, = 12.60/0.7345 = 17.15

Similarly, the other volumes are

O_2 = 9.30
c o = 5.25
HC = 6.96
N_2 = 104.43
H_2O = 31.98

In addition, there is moisture present that was in the fuel charge. This is found from

(kg of H_2O/kg of dry wood) x (moles of H_2O/kg of H_2O)
= M_w/(100 – M,) x 55.556
= 35.91 /(100 – 35.91) x 55.556
= 31.13

The amount of heat lost (enthalpy) by each product is given by

Loss = volume (enthalpy at vent temperature – enthalpy at room temperature)

In addition, the losses for CO and HC are increased by their heating value, and for H_2O by its enthalpy of vaporization.

The equations determining the total heat loss in joules/mole for each product are

CO: $22359T^{0.25} - 4015.4T^{0.5} + 69.145T - 0.012733T^{1.75}$
CO_2: $-3.7357T + 2.0353T^{1.5} - 0.02051\ 7T^{2} + (8.0660 \times 10^{-7} \times T^{3})$
H_2O: $143.05T - 46.432T^{1.25} + 5.5167T^{1.5} - 0.01\ 8495T^{2}$
0,: $(-236.88 \times 10^{4} \times T^{-1}) + (3.5714 \times 10^{5} \times T^{-0.5}) + 37.432T + (8.0408 \times 10^{-6} \times T^{2.5})$
N_2: $(-1072.7 \times 10^{4} \times T^{-1}) + (1025.58 \times 10^{3} \times T^{-0.5}) + 39.060T + (410.2 \times 10^{6} \times T^{-2})$
CH_4: $6477.6T^{0.5} - 672.87T + 111\ .25T^{1.25} - 0.4495T^{1.75}$

where
J = the temperature in degrees kelvin (degrees Celsius + 273.15)

The additional loss for CO is 282993 J/mole; for CH_4 it is 890156 J/mole; and for H_2O it is 43969 J/mole.

For example, the losses associated with the CO in kJ/kg of dry fuel are

0.001 x volume CO (enthalpy at vent temperature – enthalpy at room temperature + 282993)
= 0.001 x 5.25 (55124 – 43717 + 282993)
= 1547.1 kJ/kg of dry fuel

Similarly, the other losses in kJ/kg dry fuel are

CO_2: 286.1
O_2: 110.0
HC: 6319.0
N_2: 1182.1
H_2O_r: 1834.9
H_2O_f: 1786.3

The total loss rate is the sum of the above, or 13065 kJ/kg of wood.

Total loss over the interval = loss rate x dry weight change
= 13065 x 0.352
= 4593

The total input is CV x dry weight change
= 14188 x 0.352 = 4988 kJ

The total output = total input – total losses
= 4988 – 4593
= 395 kJ

The grams of CO produced over this interval are
(moles of CO/kg of dry wood) x (28 g of CO/mole) x (dry weight loss (kg))
= 5.25 x 28 x 0.352
= 51.7 g

The grams of HC expressed as CH, are
(moles of CH_4/kg of dry wood) x (16 g of CH_4/mole) x (dry weight loss (kg))
= 6.96 x 16 x 0.352
= 39.2 g

Similar calculations for each of the other intervals over the burn result in the following table of values:

Time, h	Initial dry weight, kg	Final dry weight, kg	Input, kJ	output, kJ	co, g	HC, g
0.26	8.20	7.90	3808	1487	10.02	-7.07
0.36	7.90	7.57	4198	373	17.33	26.43
0.44	7.57	7.24	4603	488	38.67	26.09
0.53	7.24	6.89	4988	395	51.73	39.16
0.63	6.89	6.52	5353	681	112.39	34.90
0.74	6.52	6.14	5701	2627	0.00	29.02
0.88	6.14	5.75	6035	2263	28.73	37.48
1.09	5.75	5.35	6364	2431	61.76	34.63
1.25	5.35	4.95	6698	1729	80.24	51.50
1.39	4.95	4.53	7050	1774	168.92	40.36
1.54	4.53	4.10	7436	4374	0.00	27.74
1.72	4.10	3.67	7874	3950	40.99	36.36
1.90	3.67	3.23	8384	4420	86.83	27.99
2.09	3.23	2.78	8986	3684	111.53	48.67
2.43	2.78	2.33	9706	4068	232.89	30.79
2.66	2.33	1.87	10566	8222	0.00	10.66
2.87	1.87	1.41	11594	7989	55.86	22.49
3.10	1.41	0.94	12815	9032	117.69	11.49
3.54	0.94	0.47	14257	9749	151.28	38.63
3.87	0.47	0.00	15936	10982	317.05	14.35

Note that a negative hydrocarbon value (k term) was calculated in the first data set, reducing the total losses and hydrocarbon emissions.

Summing values, the following are obtained:

Total input: 162349 kJ
Total output: 80717 kJ
Efficiency = 100 x (total output/total input)
= 100 x (80717/1 62349)
= 49.7%

The total weight of CO produced is the sum of CO production during each interval, or 1683.9 grams. The CO emissions are:

1683.9 ÷ (19.81 x 8.20) = 10.4 g/MJ

Appendix C

Total Combustible Carbon Method for Determination of Energy Efficiency of Wood Heaters

Note: This Appendix is not a mandatory part of this Standard.

(This efficiency determination procedure is the proposed Appendix J of the United States of America Environmental Protection Agency Title 40, Part 60 subpart AM of the Code of Federal Regulations.)

(Figure numbers for this Appendix have been changed to Figure (J)1 and (J)2, etc, to avoid confusion with the figures in the main text.)

1. Applicability and Principle

1.1 Applicability. This method is applicable to the determination of the overall energy efficiency and heat output rate of a wood heater. For the definition of a wood heater, see 40 CFR Part 60, Subpart AAA - Standards of Performance for New Residential Wood Heaters.

1.2 Principle. Four simultaneously-collected gas samples are collected in bags by withdrawing gas at steady rates from the wood heater stack, from the dilution tunnel (see 40 CFR Part 60, Appendix A, Method 5G), from an incinerator that oxidizes combustible gases as they are withdrawn from the dilution tunnel, and from ambient air. After the test, the carbon dioxide (CO,) concentration in each of these four bag samples is measured using an instrumental CO, analyzer. The chemical energy loss is determined using the lower heating value of the fuel and the difference in CO, concentrations of incinerated and nonincinerated dilution tunnel gas samples. The sensible energy loss is determined using stack gas temperature and stack gas flow; the total gas flow is calculated using a carbon balance relationship. The latent energy loss is determined as the theoretical latent loss, as if combustion were complete in the stove. The sensitive energy change of the stove during a test run is estimated by measuring stove surface temperatures. A series of at least four runs (as described in Appendix A, Method 28) is conducted. The final method result is- one overall energy efficiency number, which is the weighted average (as calculated in Method 28) of the results for all runs.

2. Apparatus

This method is to be used in conjunction with Methods 28 and 5G of Appendix A. Thus, the test fuel and apparatus such as the dilution tunnel: stove scale, wood scale, and fuel moisture meter are required as-specified in Section 2.2 of Method 5G and Sections 3.2 and 3.6 of Method 28, respectively. The following items are also required.

2.1 Sampling Trains. Four separate gaseous sampling trains are used. Schematics of acceptable sampling trains are shown in Figures 1, 2, and 3. Two sampling trains are essentially identical to each other (ambient and tunnel, Figure 2). The stack train, Figure 1, has a condenser (required) and dryer (optional). Dryers or condensers are not to be used in the other three sampling trains. The incinerator train, Figure 3, has an incinerator device as shown in Figures 4 and 5, and a second flowmeter. The total internal volume of each train, from sampling point to sample bag, shall not exceed 0.75 liters. Each sampling train consists of the following components:

2.1.1 Probe - Stack and Dilution Tunnel Trains Only. Stainless steel or glass about 5 to 11 mm (3/16 to 1/2 in.) I.D., and 0.15 to 0.6 m (6 to 24 in.) in length. NOTE: The ambient train needs no probe. The incinerator train probe is specified in Section 2.2.

2.1.2 Condenser - Stack Train. A glass-in-ice water condenser, consisting of one or more impingers, or one or more flasks with two-holed rubber stoppers.

2.1.3 Dryer - Stack Train. Any moisture indicating material capable of removing water from the sample gas to less than 1.5 percent moisture by volume, such as indicating silica gel.

2.1.4 Filter Holder and Filter. Any filter holder and filter suitable in Method 5G (including Section 7). Alternatively, nonreactive disposable filter canisters may be used.

2.1.5 Pressure Damper (optional). A glass flask or similar device between the sample pump and the flowmeter is optional, depending on the need to collect any water in the sampling system, or to dampen pressure oscillations from the pump, which could cause erroneous readings of the flowmeter. The flask is optional because some laboratories have found it to be unnecessary for either purpose. If a flask is used in the tunnel train, use an identical one in the incinerator train, and vice versa, to equalize response times.

2.1.6 Vacuum Gage. Any vacuum gage with a range suitable for measuring vacuum during use of the train and during leak testing of the train.

2.1.7 Leakless Sampling Pump. With associated metering valves, capable of delivering at least 0.1 liter/min (0.2 ft^3/hr).

2.1.8 Tee and Valve (optional). To permit withdrawal of a portion of the sample during a test run for continuous real time instrumental analysis.

2.1.9 Flowmeter. Any flowmeter capable of being used to maintain sample flows constant to within 10 percent.

2.1.10 **Three-Way Valve.** For evacuating the sample bag, for isolating the sample bag once evacuated, and for permitting withdrawal of sample from the bags.

2.1.11 **Sample Bag.** Air tight Tedlar sample bag, with a capacity between 50 and 100 liters. NOTE: Mention of trade names on products does not constitute endorsement by the Environmental Protection Agency.

2.1.12 **Positive Pressure System for Sample Bag.** A flat piece of material, with a minimum mass of 0.5 kg (or 1 lb) and an area on one side approximately equal to that of a deflated sample bag, capable of being placed on top of a bag in such a fashion that the bag contents are maintained at a slightly positive pressure from the start of the bag sampling run to the completion of bag sample analysis. NOTE: This system is intended to assure no contamination of the bag samples by ambient air occurs due to small bag leaks. This requirement also precludes the need for sample bag leak checks.

2.2 Incinerator System. To fully oxidize virtually all carbon containing combustibles in a sample drawn from the dilution tunnel. A typical system is illustrated in Figures 4 and 5 and consists of the following components:

2.2.1 Probe. Stainless steel, with 5 mm (or 3/16 in.) minimum ID, and no more than 3 cm (or 1 in.) longer than the radius of the dilution tunnel. Do not use any type of.filter between the probe inlet and the incinerator.

2.2.2 Incinerator Body. Stainless steel, with sample oxidizing cavity between primary input and output ports, a secondary input port for introducing bottled check gases, one or more cavities for heaters, a cavity for a temperature probe for the temperature controller, and an insulating wrap around the outside. The volume of the oxidizing cavity shall not exceed

0.15 liters. The oxidizing cavity is typically charged with catalytically-coated (e.g., platinum and palladium) ceramic beads or pellets. The probe is connected directly to the primary input'port.

2.2.3 Temperature Controller. To maintain the incinerator at a temperature of approximately 440'C (825°F).

2.2.4 Flowmeter. Connected to the secondary input port, with a capacity of at least twice the maximum sampling rate during testing and accurate to within 10 percent of the maximum sampling rate.

2.3 CO, Analyzer Sampling Train. Refer to Figure 6.

2.3.1 Vacuum Gage. To measure vacuum during use of the train and during leak testing of the train.

2.3.2 Leakless Pump. With associated metering valve(s), capable of delivering more than the flow required in the manufacturer's instructions for the CO, analyzer.-

2.3.3 Flowmeter. To measure sample flow to the analyzer, with an accuracy consistent with the manufacturer's instructions for the CO, analyzer.

2.3.4 CO, Analyzer. Any analyzer with a linearized output, meeting the specifications of Section 4, and capable of providing a measure of CO, in the range of concentrations encountered in application of this method. NOTE: Analyzers with ranges less than those specified above may be used, provided actual concentrations do not exceed the range of the analyzer. The pump used in this train may also be used for evacuating the bags. It is also permissible to use components from one or more of the sampling trains for the CO, analyzer train.

2.4 Miscellaneous Instruments.

2.4.1 Flue Temperature Monitor. Capable of measuring flue gas temperatures to within 1 percent of absolute temperature.

2.4.2 Ambient Temperature Monitor. Capable of measuring temperature to within 2°C (or 4°F) when its sensor is located centrally in a vertically oriented 150 mm (or 6 in.) long by 50 mm (or 2 in.) ID diameter pipe shield that is open at both ends.

2.4.3 Stove Surface Temperature Monitors. Five, each capable of measuring temperature to within 1.5 percent of expected absolute temperatures.

3. Reagents

3.1 Sampling. Reagents used in sampling are as follows:

3.1.1 Filters. Glass fiber filters without organic binder, exhibiting at least 99.95 percent efficiency (less than 0.05 percent penetration) on 0.3 micrometer dioctyl phthalate smoke particles. Gelman A/E 61631 filters have been found acceptable for this purpose. NOTE: In this test method, filters are used only to protect the instruments, thus filter specifications are suggestions, not requirements.

3.1.2 Silica Gel or Drierite. Same as Method 5, Section 3.1.2.

3.1.3 Crushed Ice.

3.2 Cylinder Gases.

3.2.1 CO, Calibration Gases. four gas mixtures, required for the CO, analyzer, with nominal CO, concentrations in nitrogen (N_2) as follows:

Gas Level	Concentration (Volume Percent)
High	15
Mid	1
Low	0.2
Zero	CO,-free air, or N_2 with less than 10 ppm CO,.

The gas mixtures shall be certified by the manufacturer to be accurate to within 2 percent of each component. Because the calculated chemical energy loss depends primarily on the ratios of low level CO, concentrations (as opposed to the absolute values of the concentrations), the manufacturer's certification of accuracy is deemed sufficient to meet this requirement.

3.2.2 Incinerator Check Gases. Two gas mixtures, for checking the incinerator performance, with nominal concentrations as follows:

Gas Level	Composition (Volume Percent)
Mid	0.1% CO; 0.1% CH,; balance CO,-free air
Zero	CO,-free air

NOTE: The purpose of the incinerator check gases is not to calibrate the incinerator, but to check that it effectively oxidizes combustible gases, and to check that there is no residual CO, being emitted from the oxidation of any particulate matter lodged in the incinerator. The first of the two gas levels listed above is labelled "Mid" because higher and lower actual combustible gas concentrations may be encountered.

4. CO_2 Analyzer Train Performance Specifications

For the purposes of this method, span value is defined as the upper limit of the range specified in Section 2.3.4.

4.1 Response Time. The amount of time required for the CO, analyzer sampling train to display 90 percent of a step change in the concentration of CO, entering the analyzer sampling train shall not exceed 15 seconds.

4.2 Zero Drift. The manufacturer's zero drift specification for the CO, analyzer shall not exceed 1 percent of span value over a period of 8 hours.

4.3 Span Drift. The manufacturer's span drift specification for the CO, analyzer shall not exceed 1 percent of span value over a period of 8 hours.

4.4 Resolution of Readout. The resolution of the readout for the CO, analyzer shall be at least as good as 1 percent of the measured CO, concentrations, except for measurement of ambient CO, level, in which case a resolution of 10 percent of the concentration is acceptable.

5. Incinerator Performance Specifications

5.1 Zero Check Gas Response. When CO,-free air is passed through the incinerator, at a flow rate that is at least twice the flow rate used during sampling (Section 6.2.2), the CO_2 concentration at the output of the incinerator shall be less than 0.01 percent.

5.2 Mid-Level Check Gas Response. When mid-level check gas is passed through the incinerator, at a flow rate that is at least twice the flow rate used during sampling, the measured change in CO, concentration shall be at least 90 percent of the theoretical value, based upon the actual composition of the mid-level gas used. NOTE: Ninety percent oxidation of the combustible carbon in the mid-level gas is considered adequate for the following two reasons:

5.2.1 Methane is substantially harder to oxidize than CO and most hydrocarbons found in wood smoke. Thus, a 90 percent oxidation efficiency for a calibration gas whose combustible carbon is approximately half-methane would correspond to a higher conversion efficiency for wood smoke.

5.2.2 If, in actual use in wood stove testing, the incinerator's conversion efficiency is 90 percent, the resulting error in overall energy efficiency will be less than 2 percent for a stove with a combustion efficiency of 80 percent. Most stoves that comply with particulate emission regulations will have combustion efficiencies higher than 90 percent, and hence, smaller errors in overall efficiency.

6. Procedures

Operate the wood heater as described in Method 28, Section 6. Procedures relating to the operation of the dilution tunnel are found in Method 5G, Section 4.

6.1 Pretest Preparation.

6.1.1 Leak-Checks. These procedures apply to the four gas bag sampling trains. A pretest leak check of the vacuum side is recommended but not required. A leak check of the vacuum side is mandatory at the conclusion of each sampling run. NOTE: There is no required leak check on the positive pressure side of each sampling train. A large leak would make it impossible to fill the sample bag because of its required positive pressure (Section 2.1.12). A small leak would result in loss of some sample, but should not affect the accuracy of the results.

6.1.1.1 Leak-Check Procedure. For leak checking the vacuum side of the sampling system, seal the end of the probe and use the sampling pump to create a vacuum of at least twice the maximum vacuum encountered during sampling, or 100 mm Hg (5 in. Hg), whichever is greater. NOTE: A second flowmeter (in addition to the one used for metering the sample flow into the sample bags) may be necessary to provide the accuracy needed to measure the leakage rate.

6.1.1.2 Acceptance Criterion for Leak Check. Vacuum-side leakage rate in excess of 2 percent of the average sampling rate is unacceptable.

6.1.2 Incinerator Performance Checks.

6.1.2.1 Zero and Mid-Level Check Gas Responses. Perform these checks of the tunnel incinerator at the conclusion of the collection of a set of samples for an efficiency determination. Connect the CO, analyzer train to the tunnel incinerator sampling train using the three-way valve shown in Figure 3. Turn on the pumps in both trains and pass CO,-free air through the incinerator at a flow rate typical of those used during sampling (Section 6.2.2). Note and record the analyzer response when no further change in the analyzer response can be detected. Then repeat this procedure with the mid-level check gas. If the incinerator performance specifications are not met, discard the samples and repair the incinerator. NOTE: Each check gas is introduced through the second input port to the incinerator at a flow of approximately twice that at the exit of the incinerator. This permits checking the incinerator performance without removing the incinerator probe from either the incinerator or the tunnel. The excess check gas flow exhausts through the probe.

6.1.3 Bag Evacuation. Evacuate the bags. If necessary, roll the bag up toward the fitting from the opposite corner. NOTE: If a sample bag which was last used to collect a stack sample (or other sample with comparable or higher CO, concentrations) is to be next used for an ambient, dilution tunnel, or tunnel incinerator sample, then flush the bag with ambient air *or zero* air before evacuation. If a new bag is to be used for either a tunnel or tunnel incinerator sample, then the other bag must either also be new, or purged before use with a gas containing less than 0.1 percent CO,.

6.1.4 Positive Pressure System. Check that the positive pressure system (Section 2.1.12) is in place and operational.

6.1.5 Sampling Probe Locations. Locate the flue gas probe and flue temperature probe at the center of the flue and 2.4 m (or 8 ft) from the bottom of the legs or pedestal of the stove. Locate the ambient air probe in the same air space as the stove under test, at a position approximately 1 m (3 ft) below the top of the chimney and 1 m (3 ft) from the flue. Locate the tunnel probe and tunnel incinerator probe approximately 1/4 m (1 ft) below the particulate train probe(s) location specified in Method 5G, Section 2.2.3, at the center of the tunnel.

6.1.6 Sample Train Purging. A minimum of 5 minutes before the start of each test run, turn on the pumps in all four sampling trains and use the three-way valves just before the sample bags to vent the sample flows. NOTE: Purging the sample trains serves to prevent dilution or contamination of the bag samples due to air or other gases in the sample trains prior to the start of the test run. Each vent location must be downstream of any significant sample train volumes.

6.2 Sampling.

6.2.1 Sampling Time. Sampling begins at time zero as defined in Method 28, Section 6.4.1. Start filling the sample bags rotating the valves located just before each sample bag. Turn all valves to the appropriate position within 20 seconds of time zero. End sampling at the completion of the test run as defined in Method 28, Section 6.4.6.

6.2.2 Sampling Rate. Maintain constant sampling rates into the bags to within 10 percent (see Section 9.17), and high enough to insure that the total volume of each collected sample is greater than 20 liters (or 0.7 ft^3). Operate the tunnel incinerator sampling train at approximately the flow rate required and used by the CO, analyzer during analysis of bag samples. If this flow rate is more than the desired bag filling rate, vent the excess sample, using an optional tee and valve as shown in Figure 3.

6.2.3 Use of CO, Analyzer During Test Run. If the sampling trains contain the optional tees and valves, the CO, analyzer may be used during the test run to monitor gases in the four sampling trains, as long as filling of the sample bags is not affected adversely..

6.3 Data Recording. During the test run, record the four sampling rates, the four sampling train vacuums, the flue gas temperature, the ambient temperature, and the incinerator temperature once every 10 minutes. Record the stove surface temperatures at time zero and at the end of the test run, as described in Method 28.

7. Sample Analysis

7.1 Leak Checks. A pre-analysis leak check of the CO, analyzer train is recommended but not required.. A post-analysis leak check is mandatory at the conclusion of the sample analysis.

7.1.1 Leak-Check Procedure. Seal the inlet to the CO, analyzer train. (If the inlet is connected to the three-way valves in the four sampling trains, this sealing requirement can be met by use of the three-way valve.) Use the CO, train pump to create a vacuum greater than either twice the maximum vacuum encountered during the sample analysis, or 125 mm Hg (or 5 in. Hg), whichever is greater. Record the flow indicated by the flowmeter, corrected for pressure, if applicable.

7.1.2 Acceptance Criterion. If vacuum side leakage rate is found to be in excess of 2 percent of the average sampling rate, correct the leak and reanalyze the samples, if previously analyzed.

7.2 Analyzer Train Audit. Just before (within approximately 5 minutes) analyzing the four gas samples, zero and span the CO, analyzer train with the zero and high level gases. Then introduce the mid-level gas. Using the most recent calibration curve for the analyzer, compare the measured concentration of the mid-level gas to its actual concentration. If the values do not agree to within 5 percent of their average value, recalibrate the analyzer train, then start the analyzer audit procedure over again.

7.3 Concentration Measurements. Measure the CO, concentration in each of the four bag samples at least twice. Use the following procedure. After the appropriate preparation of the CO, analyzer train (Sections 7.1 and 7.2), analyze the four samples in quick succession in the following order: ambient air, tunnel, incinerated tunnel, and then stack. Next rezero the analyzer (optional). Then reanalyze the four samples a second time in quick succession in the same order. If the two measurements of each sample agree to within their respective acceptance criteria (see Section 7.3.1), the analysis is complete. Use the average of the two measured values in subsequent calculations. If the two analyses for any one sample do not satisfy the acceptance criterion, rezero the analyzer (optional) and reanalyze all four samples a third time using the same procedure. If, for each of the four samples, at least *two* of the three analyses satisfy the respective acceptance criterion, the analysis is complete; use the average of the two analyses which fall within the acceptance criteria of each other in subsequent calculations. If, after three analyses the acceptance criteria are still not met, a need for repair of the CO, analyzer may be indicated. If no problem is found with the CO, analyzer, *reject* the samples and repeat the sample run.

7.3.1 Acceptance Criteria for Concentration Measurements. The acceptance criteria for each of the four samples are given below:

Sample	Acceptance Criterion percent of average value*
Ambient	20
Tunnel	3
Incinerated tunnel	3
Stack	2

* For example, paired stack sample analyses of 9.9 and 10.1 mole percent pass, and 9.9 and 10.2 mole percent fail. For extremely clean-burning appliances, the inexactness of the measurement process may result in a measured tunnel CO, concentration exceeding the measured incinerated tunnel concentration by up to 2 percent. If the CO, concentration in the tunnel sample is greater than 2 percent higher than the incinerated sample, consider the sample run invalid and repeat it. NOTE: If the tunnel sample CO, is between 100 and 102 percent of the incinerated tunnel CO, concentration,

record all the measured values as usual, but for subsequent calculations take the tunnel value as 99 percent of the incinerated tunnel value.

a. Calibrations and Audits

8.1 Flowmeters. Before initial use and semiannually thereafter, calibrate flowmeters by running them in their sampling trains in series with a calibrated dry gas meter. Flowmeters shall be accurate to within 5 percent at the flow rates typically used. NOTE: The flowmeters are to be calibrated as used in their sampling trains because of the possibility that pressure or flow pulsations from the sampling pumps may result in erroneous readings with certain types of flowmeters, such as rotameters. Such problems can usually be solved by inserting a surge tank in the sampling line between pump and rotameter.

8.2 Temperature Monitors. Follow the procedures as described in Method 2, Section 4.3, before initial use and semiannually thereafter. NOTE: If thermocouples are used, it is not necessary to calibrate every individual thermocouple if the following three conditions are met:

8.2.1 The thermocouples are all made with wire from a single spool.

8.2.2 The manufacturer of the thermocouple wire supplies a certificate affirming alloy uniformity such that temperature measurements are accurate to within at least 1 percent of absolute temperature.

8.2.3 A representative thermocouple, made with wire from the spool, is calibrated in accordance with Method 2, Section 4.3, on a semiannual schedule.

8.3 CO, Analyzer Train. Upon initial assembly of the CO, analyzer sampling train, perform a multipoint calibration and response time check of the analyzer train. At any time the single point audit (Section 7.2) fails, redo the multipoint calibration.

8.3.1 Set up the train and allow it to operate for a sufficient time to stabilize, as recommended by the analyzer manufacturer's published operating procedure.

8.3.2 Introduce zero gas into the inlet at the normal sample flow rate, and zero the analyzer output. Then introduce the high-level calibration gas and span the analyzer output.

8.3.3 Introduce consecutively, in the same manner as in Section 7.3, the low-level and mid-level calibration gases, and record the instrument response to each when no further change in the analyzer response can be detected.

8.3.4 Calculate and plot a linear least square calibration curve, forcing the curve to pass through the origin.

9. Calculations

Carry out calculations, retaining at least one extra decimal 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.

9.1 Nomenclature.

AF = Air-to-fuel ratio; dry combustion air mass divided by dry fuel 'mass, kg dry air/kg dry wood (lb dry air/lb dry wood).

C = Mass fraction of carbon in dry (zero moisture content) fuel; use 0.508 for Douglas fir fuel specified in Method 28, Section 4.2.

CE = Combustion efficiency, %.

C_S = Average specific heat of dry stack gas, kJ/kg-°K (Btu/lb-°R).

C_{H_2O} = Specific heat of water vapor, 1.9 kJ/kg-°K (0.45 Btu/lb-°R).

C_{STOVE} = Specific heat of stove, 0.65 kJ/kg-°K (0.15 Btu/lb-°R).

CO_{2_A} = CO, volume percent in ambient air, %.

CO_{2_S} = CO, volume percent in dry stack sample, %.

$CO_{2_{SI}}$ = CO, volume percent.in dry incinerated stack sample, %.

$CO_{2_{TI}}$ = CO, volume percent in incinerated tunnel sample, %.

CO_{2_T} = CO, volume percent in tunnel sample, %.

E_{LL} = Latent energy loss assuming complete combustion, kJ (Btu).

E_{CL} = Chemical energy loss, lower-heating-value basis, kJ (Btu).

E_{SL} = Sensible energy loss, kJ (Btu).

E_{STOVE} = Sensible energy of the stove, kJ (Btu).

E_W = Fuel wood chemical energy, kJ (Btu).

H = Mass fraction of hydrogen in dry (zero moisture content) fuel; use 0.0583 for Douglas fir fuel specified in Method 28, Section 4.2.

h = Enthalpy of vaporization of water at room temperature, use 2,442 kJ/kg (1,050 Btu/lb).

HHV = Higher heating value of the dry wood fuel; use 19,810 kJ/kg (8,516 Btu/lb).

HTE_U = Heat transfer efficiency (uncorrected for stove energy storage), %.

LHV = Lower heating value of carbon-containing combustible emissions; use 400,000 kJ/kg-mole of carbon (172,000 Btu/lb-mole of carbon).

m_d = Mass of fuel load, dry basis, kg (lb);

= $m_W/(1 + MC,,)$.

M_d = Average molecular weight of dry stack gas, kg/kg-mole (lb/lb-mole).

m_{H_2O} = Mass of water released and generated if wet fuel was completely oxidized, kg (lb).

m_S = Dry stack gas total mass, kg (lb).

m_{STOVE} = Mass of stove, kg (lb).

m_T = Total tunnel wet gas mass, computed as average wet tunnel flow times test duration, kg (lb).

m_w = Mass of fuel load, wet (as fired) basis, kg (lb).

MC, = Moisture content of fuel, dry basis, expressed as a fraction.

OE, = Overall energy efficiency (corrected for stove energy storage), %.

OE_U = Overall energy efficiency (uncorrected for stove energy storage), %.

P = Average heat output rate (power), kW/hr (Btu/hr).

Q_{sd} = Average tunnel dry volumetric flow rate (Method 2, Eq. 2-10), m^3/hr (ft^3/hr).

T_A = Average ambient temperature, °K (°R).

Ts = Average stack temperature, °K (°R).

T_{S1} = Average stove surface temperature at start of test, °K (°R).

T_{S2} = Average stove surface temperature at end of test, °K (°R).

θ = Sampling time, hr.

ρ = Tunnel gas density at standard temperature and pressure. Use 1.186 kg/m^3 (0.074 lb/ft^3).

9.2 Wood Water. Calculate the total theoretical (assuming complete combustion) mass of water vapor released and generated as follows:

$$m_{H_2O} = m_d(9H + MC,) \qquad \text{Eq. 1}$$

9.3 Stack Incinerated CO,. Calculate the dry CO, concentration which would be measured in incinerated stack gas as follows:

$$co_{2_{SI}} = CO_{2_S}(CO_{2_{TI}} - CO_{2_A})/(CO_{2_T} - CO_{2_A}) \qquad \text{Eq. 2}$$

9.4 Stack Molecular Weight. Calculate the average molecular weight of the dry stack gas as follows:

$$M_d = [44(CO_{2_{SI}}) + 32(21 - CO,_{SI}) + 28(79)]/100 \qquad \text{Eq. 3}$$

9.5 Stack Specific Heat. Calculate the average specific heat in kJ/kg •K of the stack gas as follows: Eq. 4

$$C_s = 1.003 \text{ t } 3.488 \text{ x } 10^{-5} (T, - T_A) + 2.036 \text{ x } 10^{-7} (T_S - T_A)^2$$

9.6 Dry Stack Gas. Calculate the total amount of dry stack gas as follows:

$$m_S = M_d(C)m_d/(12 \, CO,_{SI}/100) \qquad \text{Eq. 5}$$

9.7 Calculate the air-to-fuel ratio as follows:

$$AF = (m, - m_d + m_{H_2O} - m_d \, MC_d)/m_d \qquad \text{Eq. 6}$$

9.8 Stove Sensible Energy Change. Calculate the sensible energy change of the stove, ΔE_{STOVE}, as follows:

$$AE_{STOVE} = c_{STOVE} \, m_{STOVE} \, (T_{S2} - T_{S1}) \qquad \text{Eq. 7}$$

9.9 Calculate the wood energy input as follows:

$$E_W = m_d(HHV) \qquad \text{Eq. 8}$$

9.10 Calculate the latent loss as follows:

$$E_{LL} = m_{H_2O}(h) \qquad \text{Eq. 9}$$

9.11 Calculate the **sensible loss as follows:**

$$E_{SL} = [m_S C_S + m_{H_2O} C_{H_2O}](T_S - T_A) \qquad \text{Eq. 10}$$

9.12 **Calculate the chemical energy loss as follows:**

$$E_{CL} = [m_d C/12](LHV)(CO_{2_{TI}} - CO_{2_T})/(CO_{2_{TI}} - CO_{2_A}) \qquad \text{Eq. 11}$$

9.13 Calculate **the overall efficiency, uncorrected for change in stove temperature, as follows:**

$$OE_U = 100[1 - (E,, + E_{SL} + E_{CL})/E_W] \qquad \text{Eq. 12}$$

9.14 Calculate the combustion efficiency as follows:

$$CE = 100[1 - (1.03\ E_{CL})/E_W] \qquad \text{Eq. 13}$$

9.15 **Calculate the uncorrected heat transfer efficiency as follows:**

$$HTE, = 100(OE/CE) \qquad \text{Eq. 14}$$

9.16 Calculate the corrected overall efficiency as follows:

$$OE_C = OE, - (100 - HTE_U)\Delta E_{STOVE}/E_W \qquad \text{Eq. 15}$$

9.17 Calculate the heat output rate (power):

$$P = (OE_C/100)E_W/\theta \qquad \text{Eq. 16}$$

9.18 Sampling Rate Constancy. For each of the bag sampling trains, calculate the average sampling rate during the entire run from the data recorded as **described in** Section 6.3. Then calculate the **percentage deviation of each recorded sampling rate from its run average. The sampling rate is considered adequately constant if the average magnitude of the deviations is less than 10 percent and if no single deviation is larger than 15 percent.**

NOTE: **The actual calculations may be deleted if the required conditions are obviously met.**

9.18 Calculate the weighted average overall efficiency for the four runs in a manner analogous to the weighted average calculation performed in Section 8.1 of Method 28. Use this weighted average value to report the overall efficiency of the wood heater.

10. Data Quality Checks

If any of the following inequalities are not satisfied, an error in the data is likely.

10.1 Ambient CO,:

$$0.03 < CO_{2_A} < 0.1$$

10.2 CO, concentration ordering:

$$0 < CO_{2_A} < co,, < CO_{2_{TI}} < CO_{2_S}$$

10.3 Carbon recovery fraction:

$$.85 < f < 1.15$$

where:

$$f = [(CO_{2_{TI}} - CO_{2_A})/100]\,(12/29)m_T/(C\ m_d)$$

and:

$$m_T = 1.04\ Q_{sd}(\theta)(\rho)$$

<u>NOTE</u>: The factor 1.04 converts Q_{sd} from dry to wet basis under the assumption of 4 percent moisture in the dilution tunnel, as permitted in Method 5G.

11. Bibliography

1. Jaasma, D.R. and J.W. Shelton. Technology For Efficiency Measurement of Woodburning and Other Solid Fuel Appliances: Phase II Report. U.S. Department of Energy, Washington, D.C. Prepared under grant number DE-AS05-83CE23858. March 1987.

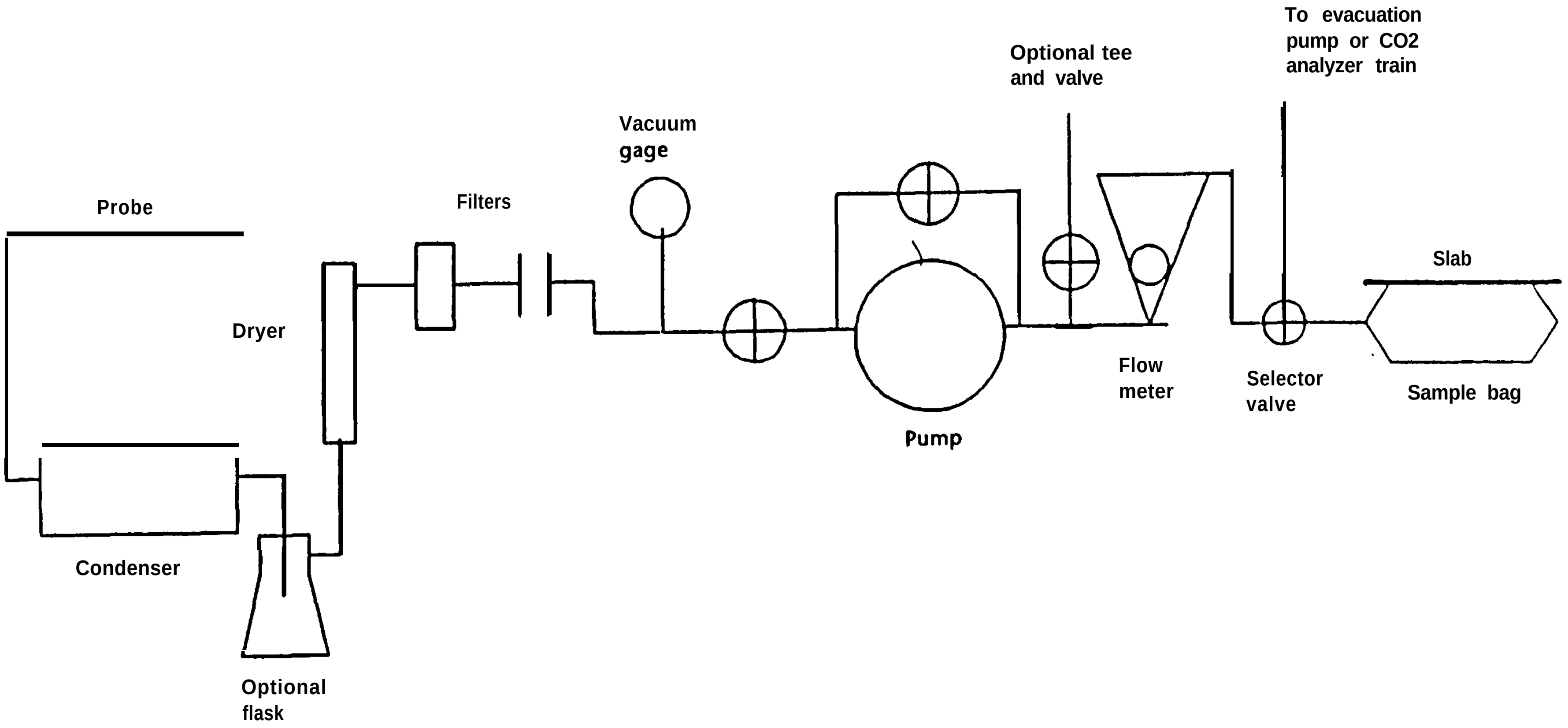


Figure (J)1
Stack Sampling Train

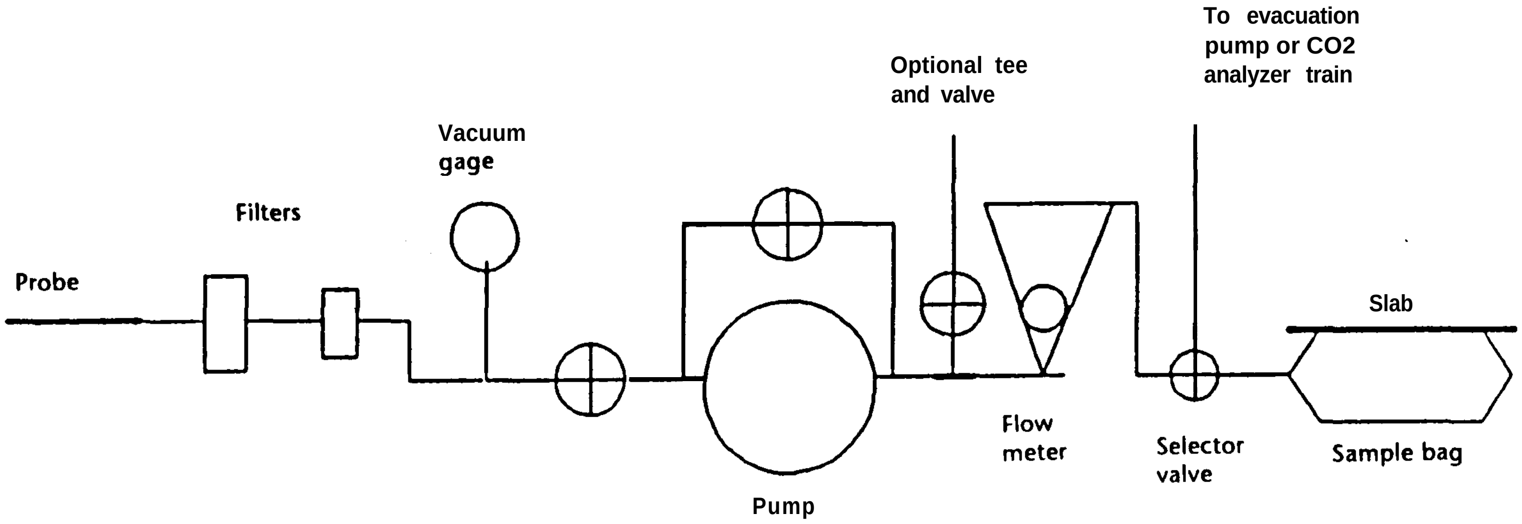


Figure (J)2
Ambient and Tunnel Sampling Trains

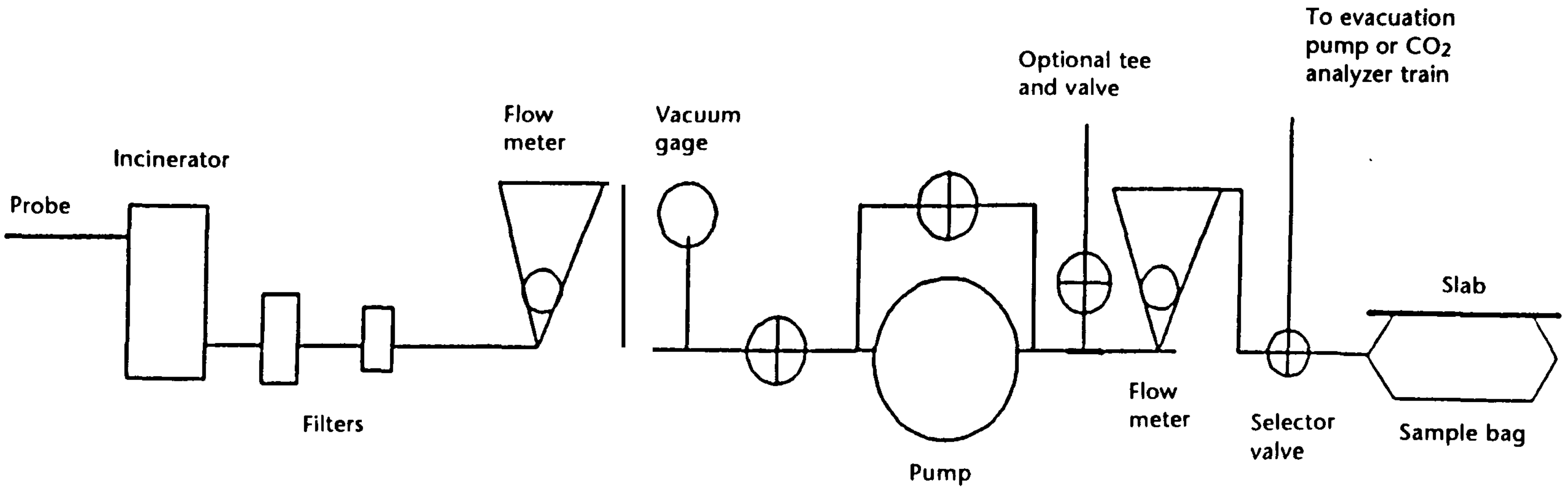


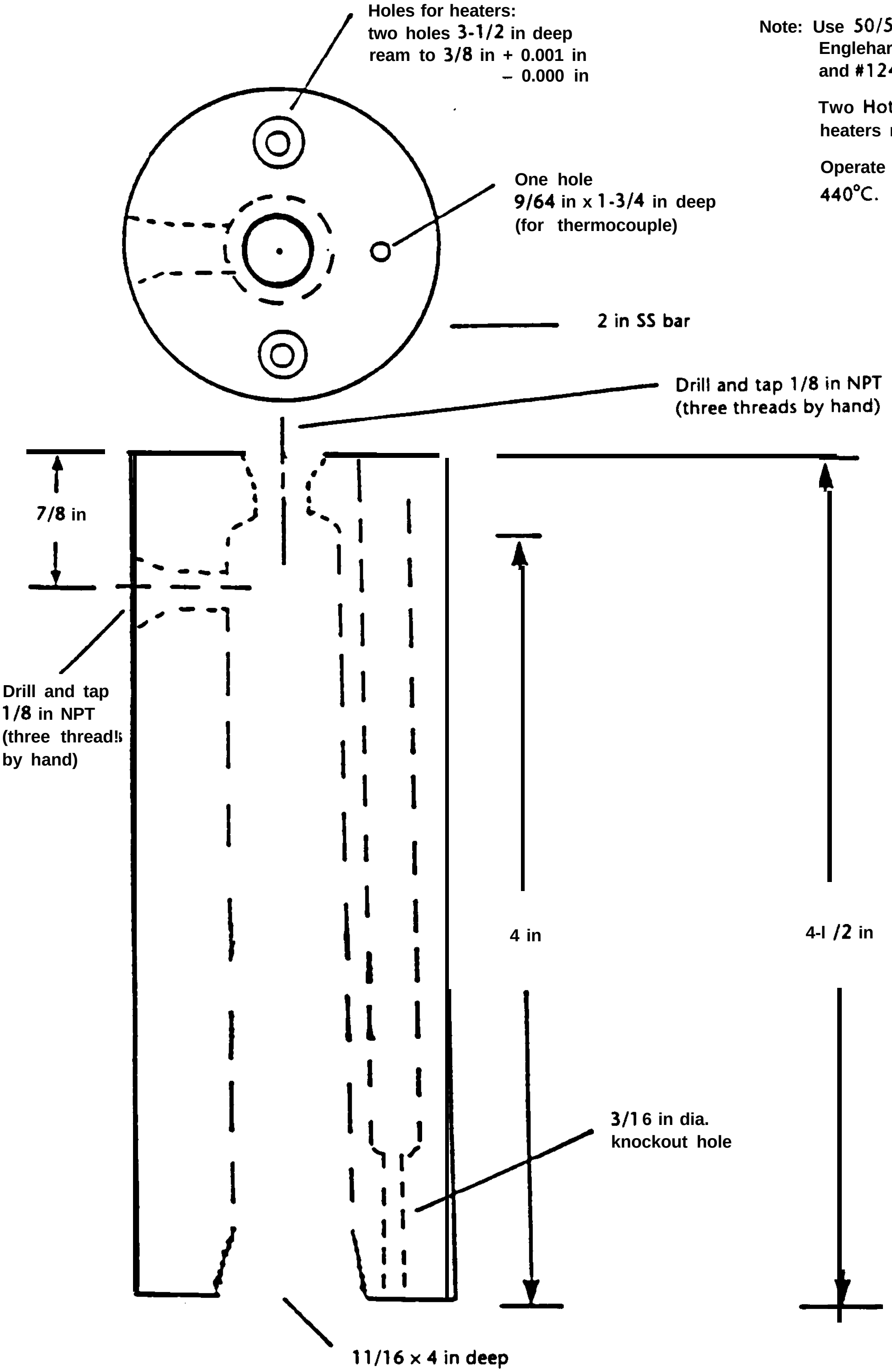
Figure (J)3
Tunnel Incinerator Sampling Train

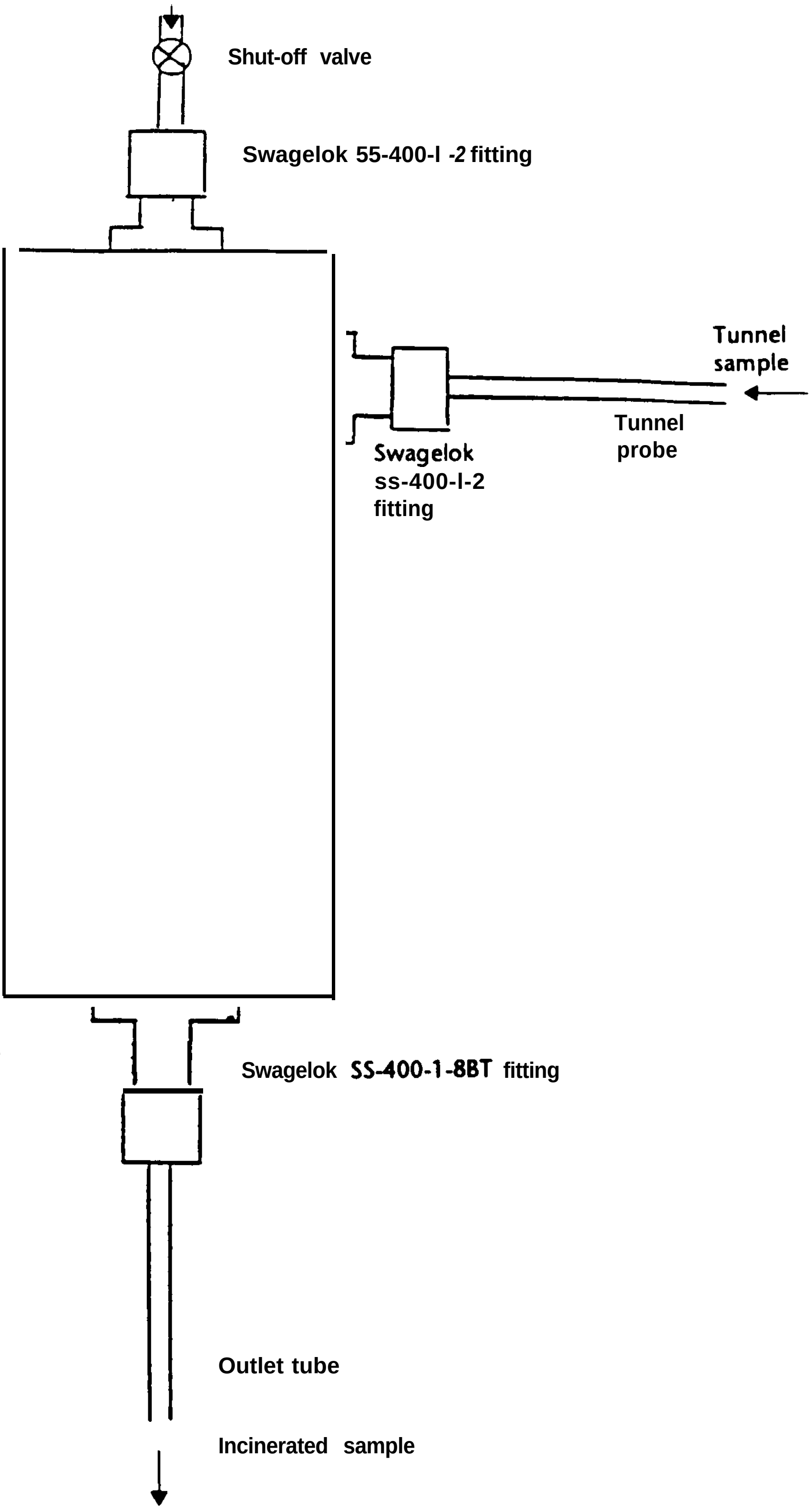
Figure (J)4
Catalytic Incinerator

Note: Use 50/50 mix of Englehard #2253701 and #1243801 catalysts.

Two Hotwatt #SC3755 heaters required.

Operate incinerator 440°C.





Note: Insert outlet tube so tube protrudes 1/2 in past the outlet fitting. Cross drill tube with two holes and close end of tube so catalyst pellets cannot clog tube.

Figure (J)5
Incinerator With Gas Hook-Ups

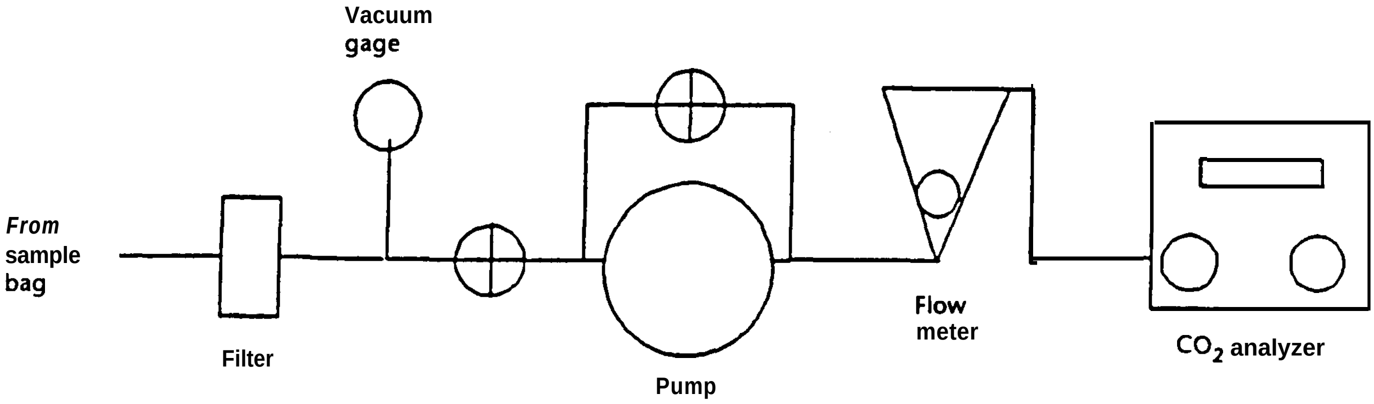


Figure (J)6
CO2 Analyzer Train

***Proposal** for Change*

To help our volunteer members to assess proposals to change requirements we recommend that each proposal for change be submitted in writing and identify the
(a) Standard number;
(b) Clause number;
(c) proposed wording of the Clause (requirement, test, or pass/fail criterion) using mandatory language and underlining those words changed from the existing Clause (if applicable); and
(d) rationale for the change, including all supporting data necessary to be considered.

The proposal should be submitted to the Standards Administrator at least one month prior to the next meeting of the Committee. It is CSA Committee practice that only those proposals sent out to members prior to a meeting can be the subject of discussion and action. This is to allow the members time to consider the proposal and to do any research they may feel necessary.

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