A Comparison of Masonry Fireplace Emission Testing Methods

prepared for:

The Brick Institute of America
Reston VA 22091

prepared by:

Norbert Senf
Masonry Stove Builders
RR 5
Shawville, Québec J0X 2Y0

September 23, 1995

EXECUTIVE SUMMARY

Masonry fireplaces are starting to face atmospheric emissions regulations, with particulate matter (PM) emissions of most concern to regulators. Site built masonry fireplaces are already outlawed in most of Colorado and parts of Nevada, California and Montana. This means that new fireplaces cannot be built unless they are certified to have PM emissions below limits defined by individual jurisdictions. There is currently no clearly defined method for certifying fireplaces. In addition, the definition of PM for US-EPA regulated appliances is dependent on the measuring method used. Therefore, different measuring methods would be expected to yield differing values.

In an attempt to address these issues and also deal with impending regulation of fireplaces in Fresno county, considered a bellwether jurisdiction in California, Western States Clay Products Association recently sponsored a series of comparison tests there on two fireplaces, using three different emissions measuring methods simultaneously.

Test results for PM emission factor (g/kg) showed a reasonable agreement between methods, given the limited number of tests and other variables. Results for PM emission rate (g/hr) were more variable because each test method uses a different burn rate definition. Valuable hands-on insight was gained by members of the masonry fireplace industry into the complex issues involved in the testing of woodburning fireplaces. A summary of test results is given in Table 5 and shown graphically in Figures 1 and 2.

Two fireplaces were tested, an open Rumford fireplace and a Rosin fireplace with airtight glass doors. An air supply and fueling protocol were demonstrated in a certification test for the glass door fireplace that reduced particulate emissions to well below the level required by current United States Environmental Protection Agency requirements for woodstoves.

Test method features are compared and some individual strengths and weaknesses in their applicability to fireplace testing are identified. Suggestions are made for improving data compatibility in future testing.

TABLE OF CONTENTS

INTRODUCTION

Woodburning regulation

Wood combustion is an extremely complex process chemically, and is not completely understood. Therefore, terms of reference have to be chosen with great care if meaningful comparisons are to be drawn. The current playing field was defined when the United States Environmental Protection Agency (US-EPA) promulgated an emissions definition and test method in 1988. The value of earlier literature for comparison of particulate matter (PM) data is limited.

In 1992, US-EPA legislated mandatory emissions testing for woodstoves. The US-EPA definition of a woodstove was fairly narrow, with the result that masonry fireplaces are classed as “non-affected facilities”. Furthermore, the two specified laboratory emissions test methods are unusable for masonry fireplaces on technical grounds. Woodburning was seen as a contributor to PM pollution of the atmosphere in several sensitive airsheds that were in non-attainment of federal Clean Air Act standards and therefore likely to be a public health concern. Although it can be argued that wood is in fact potentially a clean-burning fuel, the ratio between PM emissions during ideal and non-ideal (smoldering) combustion conditions can be two orders of magnitude.

The US-EPA test methods for regulated appliances (woodstoves) are inapplicable for masonry fireplaces and heaters - burn rate is determined by placing the appliance on a scale; the hygroscopic nature of masonry makes the required resolution unfeasible. This soon became a problem when clean appliances such as masonry heaters were required to show “equivalent to US-EPA certified” data by local jurisdictions in California, Colorado, Washington and Nevada. US-EPA has decided that “equivalent to” data can only be in the form of audited in-home field test data, since no laboratory method has gained its recognition.

This is the case for masonry fireplaces also. If any clean burning designs are discovered or developed, the onus will be on the industry to provide proof in the form of field test data that is acceptable to the particular authority in question.

Current EPA activity in regulating wood heating seems to be winding down, with no major changes visible on the immediate horizon. Regulatory activity is shifting to the state and local level instead. This is because non-attainment airsheds must demonstrate a State Implementation Plan (SIP) to attain Clean Air Act standards or risk losing federal funds.

The first skirmish in this area took place in Colorado in 1993, where state health authorities adopted a fairly hard-line approach in dealing with masonry fireplaces and masonry heaters. Although a vigorous and timely industry effort eventually achieved a compromise for masonry heaters, this did not happen for masonry fireplaces.

In contrast with the adversarial stance taken by Colorado, Washington state demonstrated a more enlightened approach in 1995 in proposing regulations that will force all new masonry fireplaces to become emissions certified by 1997. State regulators were prepared to proceed in a cooperative effort with an ad-hoc technical advisory group (TAG) to implement the Washington Clean Air act through the State Building Code.

Air quality regulation in California is done at the county level, and jurisdictions are currently looking to Fresno county to take the lead in promulgating air quality regulations for fireplaces. Because of the potential for the masonry industry to lose all of its masonry fireplace business in the county (and likely the state), the deadline for a regulation has been extended to 1997 in order to give the industry more time to respond. The focus for the testing work described in this report is the state of California

History of masonry fireplace testing

Emissions testing of masonry fireplaces started only recently[1,2] Early work at Virginia Polytechnic Institute (VPI) was instigated by the Masonry Heater Association of North America (MHA) and supported by the Wood Heating Alliance (WHA), the factory fireplace manufacturers’ caucus, and the masonry industry through the Brick Institute of America (BIA). It came as a response to the impending US-EPA regulation of emissions for woodstoves. It soon became apparent that the masonry industry needed a database on more specific masonry fireplace performance issues. It was felt that the industry would be wise to take a pro-active approach to the possibility of future inclusion of fireplaces in the regulations, particularly since the early news on fireplace emissions levels was not good. Answers to very fundamental questions were unknown, and the literature in this area was empty.

Subsequent to the VPI work, Western States Clay Products Association (WSCPA) sponsored a project by OMNI Environmental to obtain in-home field test numbers for masonry fireplaces[3,4]. These projects were necessary first steps and laid valuable groundwork in the areas of developing testing protocols and establishing baseline emissions factors for masonry fireplaces and heaters in the field.

WOOD BURNING EMISSIONS MEASURING METHODS

US-EPA methods

Two types of test method define the EPA woodstove standard, a laboratory fueling protocol and a PM sampling method.

The laboratory fueling protocol is known as Method 28 (US-EPA-M28). It specifies standardized fuel cribs that are assembled from douglas fir dimensional lumber. It also specifies a method for establishing a series of standardized burn rates by placing the stove on a scale and adjusting the combustion air supply setting. Emissions during the cold start phase are not addressed, and a hot-to-hot burn cycle, starting and finishing with a charcoal bed, is used.

PM is defined by two different methods in the 1988 EPA rule, Method 5G (US-EPA-M5G) and Method 5H (US-EPA-M5H).

The following description of the two PM measuring methods is taken from the regulation:

> **US-EPA-M5G**. Particulate matter is withdrawn proportionally at a single point from a total collection hood and sampling tunnel that combines the wood heater exhaust with ambient dilution air. The particulate matter is collected on two glass fiber filters in series. The filters are maintained at a temperature of no greater than 32°C (90°F). The particulate mass is determined gravimetrically after the removal of uncombined water.
>
> **US-EPA-M5H**. Particulate matter is withdrawn proportionally from the wood heater exhaust and is collected on two glass fiber filters separated by impingers immersed in an ice bath. The first filter is maintained at a temperature of no greater than 120 °C (248 °F). The second filter and the impinger system are cooled such that the exiting temperatures of the gas is no greater than 20 °C (68°F). The particulate mass collected in the probe, on the filters, and in the impingers is determined gravimetrically after removal of uncombined water.

US-EPA-M5G uses a dilution tunnel which mixes the stove exhaust with atmospheric air before sampling. This most closely resembles the real world, where some of the hydrocarbons only condense into smoke particles after being cooled in the atmosphere. The cooled and diluted sample is passed through a set of filters that collect the particulate. In US-EPA-M5G, a hot sample is drawn directly from the stack. The particulate is collected in fractions by passing the sample in series first through a hot filter, then through several cold impingers and finally through a cold filter.

US-EPA-M5H is more complicated to implement and is considered as a reference method. US-EPA-M5G is used more in actual practice. Empirical data at the time the regulation was written (1988) indicated that the methods produced differing PM numbers, and the rule defines a conversion factor between the two.

Methods for measuring emissions in the field

Two field sampling techniques have been recognized by US-EPA to date. These are **the VPI Field Sampler** and the **AES** (Automated Emissions Sampler) developed by OMNI. Both methods have been calibrated to US-EPA-M5G. The most recent calibration has been with the VPI Field Sampler, showing a very robust correlation to US-EPA-M5G. The AES, on the other hand, has a more extensive in-home track record.

Unfortunately, neither of these methods is ideally suited for developing large performance databases. There are two reasons. First, both methods are expensive if large numbers of tests are involved. Secondly, neither method has a fast enough turnaround time to provide the immediate feedback that is needed for the timely adjustment of test parameters during research and development. Furthermore, resolving data on a per-burn basis rather than a per-week basis is expensive.

The third method, US-EPA-M5G itself, does not lend itself very easily to field testing due to the use of a dilution tunnel which is not easily portable in its specified form.

A fourth sampling method, the Condar Method (recognized officially in Oregon as Oregon Method 41 (OM41)) has been used by the author and colleague Jerry Frisch to build a masonry heater and masonry fireplace performance database at Lopez Labs. Main features of OM41 are simplicity and low cost. A drawback is the lack of enough US-EPA-M5 comparison data for OM41. This is an obstacle to obtaining recognition for in-home field data obtained with OM41.

The main purpose of the test series described in this report was to compare three of the above test methods, US-EPA-M5G, AES, and OM41 for their relative merits in measuring masonry fireplace emissions.

An interesting discussion of the relative merits of OM41 from a US-EPA perspective is found in the preamble text of the actual regulation: (the author's comments appear in italics)[5]

> One commenter argued that the Oregon Method 41 (OM41) should be allowed as a compliance test method for the wood heater regulation because of being less expensive and easier to use. Eight commentators petitioned the Agency to approve the use of OM41 for QA testing, noting that the method is recognized in Oregon as equivalent to Oregon Method 7. Comments made in support of OM41 included: (1) A significant amount of data from simultaneous tests with OM41 and Oregon Method 7 verifies the high correlation between the results of the two methods; - (2) the initial cost of implementing OM41 is half that of either Method 5H or 5G; (3) OM41 uses short-interval sampling and provides instantaneous results, two factors valuable in diagnosing and evaluation of wood heater design; (4) OM41 is easy to prepare, calibrate, and operate with limited technical training; (5) OM41 samplers have been calibrated by the manufacturer to produce a standardized instrument for the industry, as opposed to the EPA methods which must be calibrated frequently on site; and (6) OM41 equipment is compact and portable.
>
> EPA has considered this test method, but is not approving it for certification or QA testing....Deficiencies include: (1) The data reported in the literature comparing the OM41 results with other test method results do not include many values in the range expected for compliance testing of NSPS wood heaters (<10 g/hr). (2) The OM41 sampling rate is not proportional to the flow rate in the wood heater stack, which is necessary for accurate measurement; (3) sample volume is not measured directly, but is calculated from orifice readings *(author's comment: this is not entirely true— the orifice and manometer are factory calibrated as a system)* (4) the stack gas flow rate is not determined using a carbon mass balance approach as is used in the Oregon DEQ and the Method 5H procedures; and (5) the dilution temperature in the OM41 sampler is dependent on the temperature of the wood heater and, thus, is a variable *(author's comment: a thermocouple tracks tunnel temperature which is always lower than 90 ºF, as inUS-EPA-M5G)*
>
> Another reason is that there was no suggestion or support during the negotiations for the inclusion of OM41 as a third test method for either certification or QA testing purposes.
>
> Test methods are an integral part of any regulation and the emission limit is related directly to the method. This is especially true for PM because PM is not an absolute quantity, but rather is defined by the test method. Application of more than one test method to a regulation needlessly complicates enforcement and may even result in unequal enforcement of the standards. Because of these considerations, the regulatory negotiation process for the wood heater regulation resulted in two certification test methods with a correlation factor for comparability of the two method's results.
>
> Wood heater manufacturers may continue to use OM41 for a number of internal purposes. These include collection of interval emission samples and sampling during field evaluation. For the reasons cited above, the OM41 method is not acceptable for use in QA tests that manufacturers are required to perform.
>
> (p 5870) One commenter raised the issue of how EPA would deal with a manufacturer who wanted to have an exempt appliance certified. An appliance that is not an affected facility is not regulated. With limited resources, EPA does not intend to certify appliances which are outside the scope of the regulation's coverage.

THE 1995 WSCPA TESTS - COMPARING EMISSIONS MEASURING METHODS

Introduction

This report details a series of tests performed in March, 1995 at a test facility provided by The McNear Brick Co. in San Rafael, CA (Fresno county). The testing was funded by WSPCA.

Two masonry fireplaces were studied, and three separate test methods - US-EPA-M5G, AES, and OM41 - were run simultaneously on both fireplaces.

Atmospheric pollutants studied

Two pollutants are currently the focus of air quality regulation with residential wood combustion - carbon monoxide (CO) and particulate matter (PM). Carbon monoxide is generally not considered to be a major public health concern with woodburning, and PM is the main focus of regulatory activity. PM is further specified to be particulate matter smaller than 10 microns (PM10). At this scale, particles can pass directly through the lungs into the blood stream and therefore become more of a health concern than larger particles, for example road dust. Visible woodsmoke consists of small droplets of tar, 90% of which are smaller than 1 micron. The phenomenon of air quality impairment from residential wood combustion is therefore easy to identify qualitatively as visible haze with the distinct odor of woodsmoke.

The test methods under discussion are methods for measuring PM emissions. The basic process is to pass a portion of the flue (exhaust) gas through a filter. The desiccated filter is weighed on an analytical balance before and after the test.

Although the basic principle is simple, there are a number of complications. The main one arises from the fact that woodsmoke is a complex and variable mixture of chemical compounds. As the hot flue gas leaves the chimney, it mixes with air and cools. This results in the condensation of a number of semi-volatile gases into droplets of tar. In other words, the composition of the smoke is changing continuously as it leaves the chimney. The goal of all three test methods under discussion is to provide a measurement that reflects, to a greater or lesser degree, how much condensed wood smoke actually ends up loading the airshed with particulates. A second emissions component, volatile organic compounds (VOC's) that remain in gaseous form, is excluded from the definition of particulate. One would expect the PM/VOC mix reflected by the filter catch (PM portion) to be influenced by the exact time/temperature/dilution pathway taken prior to being collected.

DESCRIPTION OF THE EMISSIONS MEASURING METHODS USED

AES

The AES unit is a portable emissions sampling system. Flue gases are drawn from the stack about 6 ft above the base of the firebox. The sample travels through a Teflon tube from the stack collection point to the sampler, where it is passed through a heated filter for collection of particulate matter. The filter is followed by a cartridge containing a sorbent resin for collecting semi-volatile hydrocarbons. Flue gas concentrations are measured by a Lynn electrochemical cell.

A calibrated orifice is used to maintain a 1.0 l/min. sample flow. A subsample of this flow is pumped into a 22 liter Tedlar bag for laboratory analysis of average carbon dioxide and carbon monoxide concentration and to confirm average oxygen concentration as measured in the field.

Various pumps and solenoids on the AES are operated by a digital data acquisition and control system. The AES system operates automatically for the duration of the test period (typically one week) except for daily input of fuel weight data. For the California tests, the AES was run in a daily mode in order to yield discrete data on individual burns.

US-EPA-M5G

The test method used at McNear Brick is a modified version of US-EPA-M5G. The dilution tunnel is consistent with US-EPA-M5G and comprises a collection hood over the chimney top and a 20 foot long, 10 inch diameter U shaped pipe connected to a large exhaust fan. The flow rate in the tunnel is chosen to insure that all exhaust is collected from the chimney, and that it is mixed with enough air and cooled so as to simulate actual smoke formation in the atmosphere.

An accurate flow meter is used to collect a known fraction of the known tunnel flow through a filter train consisting of conditioning system and fiberglass filters. Dual filter trains are used for data redundancy. The filters are desiccated and then weighed on an analytical balance. The filter train components and tubing are rinsed with acetone and, after evaporation of the acetone, any resulting residue is also weighed. The filter train used for these tests is substantially similar to the official EPA Method 5G (M5G) train defined in the Federal Register.

OM41 (Condar Method)

The OM41 sampler is a dilution tunnel. It consists of an approximately 6” long sheetmetal cylinder 6” in diameter. A short probe samples flue gas approximately 8 feet from the flue entry. Gas is drawn through a calibrated orifice and immediately into a mixing chamber. Negative pressure in the mixing chamber draws ambient air through a number of orifices to yield a mixing ratio of 20:1 at constant pressure. From the mixing chamber, cooled gases are drawn through a pair of 6” fiberglass filters. Filters are changed at 15 minutes into the burn. This provides information on PM emissions during the cold start phase. An exhaust fan at the rear of the tunnel provides the negative pressure to draw the exhaust gas through the filters. Pressure at the calibrated sampling nozzle and mixing chamber is held constant by manually adjusting the fan speed with a Variac control in response to a manometer. Tunnel flow is held constant at 0.19 litre/sec.

A separate flue gas sample stream from a nearby stack location is pumped through gas analyzers for oxygen, carbon dioxide, carbon monoxide and hydrocarbons. The CO_2 and CO values are used in conjunction with stack temperature to calculate CO and PM emissions factors from filter catch weights. Efficiency values are also calculated. Calculations are based on formulas developed for OM41 by the late Dr. Stockton (Skip) Barnett of OMNI Environmental. They are intrinsically compatible with AES calculation methods.

OM41 has been modified at Lopez Labs to better address masonry fireplace and masonry heater testing. In accordance with the EPA requirement for field data for non-affected facilities, a field testing fueling protocol using douglas fir cordwood has been developed. With the Lopez protocol, comprehensive documentation of the fuel charge is used. Each stick of wood is measured for moisture, weight, length and circumference. A photographic record shows each individual piece of wood as well as its position in the firebox. The actual configuration of the fuel charge is not specified, but rather is documented thoroughly enough to be reproducible at a later time.

Burn rate determination is done by the simple expedient of specifying a 2 hr. test. In order to reduce testing costs at Lopez Labs, a test equipment configuration was developed that allows up to 4 test runs per day on 4 separate appliances. A standardized 2 hour burn time was therefore chosen. This was considered to be realistic for high burn rate devices such as masonry heaters, since the fuel load is almost, if not completely, burned and any remaining “tail end” to the burn would yield very little data compared to the actual burn. While one would expect an effect (likely consistent) on efficiency numbers, one would not expect an effect on PM factor. Fireplace testing parameters were chosen to be compatible with this method, and this is admittedly a subset of the wide range of combustion conditions possible with wood burning fireplaces.

This arbitrary redefinition of the cold to cold burn time affects calculated PM rates but not PM factors.

Table 1. Comparison of emissions measuring method features

	US-EPA-M5G	AES	OM41
EPA recognized for fireplaces?			
Field testing	N/A	Yes	No
Laboratory testing	No	No	No
PM data turnaround time	1 day	3 days	1 day or real-time
Sensitive to O_2 at high dilution ratios (open fireplace)	No	Yes	Yes
Also yields efficiency data	No	Yes	Yes
Also yields CO data	Yes, real-time	Yes, average	Yes, real-time
Measurement period	cold to cold	cold to cold	2 hr. (Lopez)
Precision of results	no data	dependent on excess air factor	dependent on excess air factor
Portable	No	Yes	Yes

FIREPLACES TESTED

Frisch Rosin

The Frisch Rosin fireplace is based on the Rosin firebox, developed in 1939 by Professor P.O. Rosin at the Institute of Fuel in Great Britain. Rosin built elaborate fluid models using dye streams in a transparent water tank to study the aerodynamics of domestic open fires. Using the principles of dimensional analysis, he translated his findings to full scale masonry fireplaces. It consists of a curved precast refractory firebox and a refractory hood. It has no smoke shelf. In the Frisch-Rosin design, an airtight glass door is added to the basic Rosin. The main feature is the fixed combustion air supply. It consists of a 1” i.d. air tube on either firebox sidewall that is aimed directly at the fire. The air supply rate is not adjustable. The fireplace had a 30" wide × 30" high opening, an 8" × 12" clay lined flue and a chimney height of 18 feet.

Buckley Rumford

The Buckley Rumford uses the traditional Rumford firebox design. The Rumford fireplace was developed by Count Rumford in the second half of the 18th century. Initially designed as a retrofit for the huge fireboxes of the day, it gained wide popularity. It reduced the depth of the firebox considerably and added splayed sides. This increased the radiation of heat into the room considerably. It also added a throat and a smoke shelf.

The Buckley Rumford is true to the original Rumford design in that it has a straight firebox back. An important feature in the Buckley Rumford is a curved chimney breast beginning at the trailing edge of the top of the fireplace opening. Rosin’s aerodynamic models clearly show eddies at this point for a standard fireplace with a square edge. A gradually curved chimney breast results in a smooth transition to a 4” throat approximately 12” above the opening. Proponents of the Rumford design, like the Rosin, also claim that firebox opening to flue cross-section ratios can be used that are considerably higher that the 10:1 to 12:1 ratios promulgated in many building codes. A Buckley Rumford fireplace with a 30" wide × 30" high opening, an 8" × 12" clay lined flue and a chimney height of 18 feet was used for the McNear tests.

TESTS PERFORMED

Frisch Rosin fireplace

Prior to the tests at McNear Brick, 26 tests spread over two years were performed on the Rosin fireplace at Lopez Labs. Four of these tests were with the same combustion air configuration (Frisch) that was used for the McNear tests. Subsequent to the McNear tests a series of 9 tests was run at Lopez Labs on a standard site-built fireplace using the Frisch air supply. All tests with the Frisch air supply were run with the airtight glass doors closed and with identical fuel configurations, with the fuel load kindled from the top ("top down" burn).

Buckley Rumford fireplace

A total of 7 test runs were done on the Rumford fireplace at McNear Brick. All runs were in the open fireplace mode. All 3 test methods were used for 3 tests. Dilution tunnel only was used for 3 tests. For one test there is tunnel and OMNI data. Fueling for the Buckley Rumford tests was variable and is summarized in Table 2.

Data used for this report

A total of 18 tests were run at McNear brick, including conditioning runs on both fireplaces. Data for this report is taken from a summary of AES data provided by OMNI and from copies of the original lab notes for the US-EPA-M5 and OM41 data.

The purpose of this test series was to compare test methods, and 9 test runs used 2 or more test methods simultaneously. Data from the last 6 of these tests is used for this report. There were startup problems during the first three tests.

TEST RESULTS

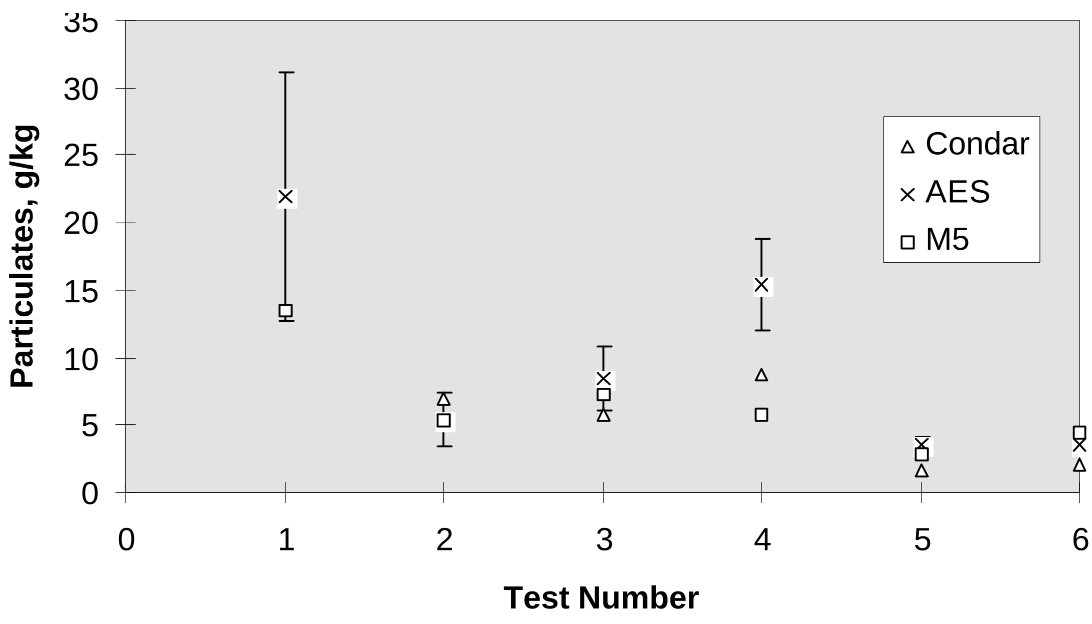

Figure 1. PM emission factor, comparison of three test methods

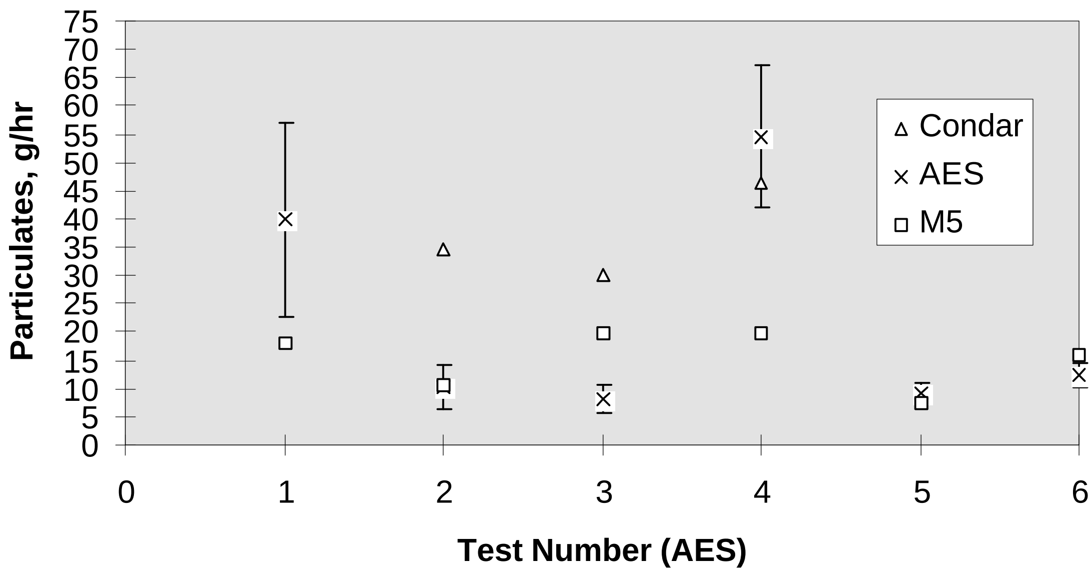

Figure 2. PM emission rate, comparison of three test methods

Figure 1 and Figure 2 summarize the PM factor and PM rate results, respectively, for the 6 comparison tests. Tests 1—4 are on the open Rumford, and tests 5—6 are on the closed Rosin.

A data summary is given in Table 5, below.

TESTING ISSUES

Precision and accuracy

The OMNI data was reported by OMNI with an error margin, shown on the graphs as error bars. No details were given. Data for the other tests was obtained as unedited laboratory notes. For the US-EPA-M5G data, Dr. Jaasma has given a rough estimate of +/- 20% due to environmental and time factors that precluded the use of quality control to EPA standards. For the OM41 data, a suspected leak in the gas analysis train would by itself give an estimated +50/-0 % uncertainty in gas readings This precludes calculation of a correction factor for the open fireplace data due to increased dependence on oxygen measuring accuracy at high dilution levels, discussed below. A discussion of other error issues is given below.

It should be noted that this test series is the first time that an attempt has been made to run these three test methods not only simultaneously, but also under field conditions. A detailed analysis of accuracy and precision for this data set is beyond the scope of this report and likely unwarranted. The extreme field conditions by themselves introduced an element of uncertainty.

Fueling protocol

The Lopez Labs fueling protocol was used for all of the Frisch Rosin tests. Fuel was Douglas fir cordwood, 16 inches long, split down into roughly 4" × 4" pieces from large diameter old growth boles. All tests used an identical stacking method. The first tier of the wood charge consisted of two spacer pieces approximately 1" × 1" laid transversely. Tier 2 consisted of 3 pieces of cordwood stacked front to back. Tier 3 consisted of 2 pieces of cordwood laid transversely. The fuel charge mean weight, excluding kindling, was 13.2 kg with a standard deviation of 3.0 kg. Kindling weight for all tests was 1.36 kg. (3 lb.). Kindling and balled up pieces of newsprint were distributed in the middle and at the top of the main fuel charge. Ignition was from the top of the fuel charge (“top down burn”).

Fueling method for the Buckley Rumford was variable and is summarized in Table 2

Table 2. Fueling for Buckley Rumford tests

Test date and number	Fuel type	Fuel moisture, %	Stacking method	Gas log lighter used
3-6-95-S1	douglas fir	pc 1 10% surface, 20% interior pc 2 10% surface, 14% interior	log cabin	yes
3-7-95-S2	douglas fir	19	teepee	no
3-7-95-S3	douglas fir	missing	log cabin	yes
3-8-95-S1	douglas fir	missing	log cabin	yes
3-9-95-S1	Presto log (“Ecolog”)	11.6	N/A	no
3-9-95-S2	“big cored wood”	17.0	N/A	no
3-10-95-S1	hardwood	9.0	teepee, fell apart	?

Reporting units: emission rate vs. emission factor

The EPA regulation specifies woodsmoke quantity as a mass (grams). The emission unit defined is a rate, grams per hour (g/hr). PM emission values are stated in this report both as a rate, g/hr and as a factor, g/kg.

Burn rate definition

Each of the three test methods used for the tests at McNear Brick uses a different burn rate definition. In all cases, burn rate equals the total fuel charge (minus unburned fuel), divided by the duration of the burn. The problem that arises is in defining when the fire is out. Field tests are always cold-to-cold, whereas EPA tests are hot-to-hot, i.e. starting and ending with a charcoal bed. Reference to US-EPA-M5 and OM41 in this document is to emissions measuring only and not to burn rate definition.

US-EPA-M5(McNear): the burn is defined as ended when the CO concentration in the tunnel drops below 5 PPM.

AES: the burn is defined as ended when the stack temperature drops below 100 F.

OM41(Lopez Labs): the burn is defined as being 2 hours in length, and applicable only to high burn rate appliances.

Table 3. Comparison of defined burn times for the 6 comparison tests

	Test number (AES)					
Burn Time, h	1	2	3	4	5	6
OM41		2.0	2.0	2.0	2.0	2.0
AES	2.4	4.8	9.6	2.7	3.8	3.8
US-EPA-M5G	3.0	4.8	2.9	2.7	3.8	3.8

It is evident that the three test methods differ in burn times, depending on definition. It should be noted that when testing masonry appliances, a considerable amount of heat is stored in the masonry mass and that, unless a tight chimney damper is used, the stored heat will maintain chimney temperatures and draft until well after the fire is out. For the AES, a test with an ambient temperature of 80 F will result in a longer burn time than a test with an ambient temperature of 32 F. Dampers were left open for all testing at McNear Brick.

A comparison of g/kg emission factors with g/hr emission rates for the three different test methods is shown below. While the PM factors are in reasonable agreement, we see a wider spread in PM rates.Sensitivity to high combustion air dilution ratios

Two of the test methods, the AES and OM41, rely on a measurement of stack oxygen to determine an emission factor or rate. As the stack oxygen approaches ambient (20.9%), the dilution ratio increases exponentially. In other words, to maintain accuracy at high dilution rates the resolution of the oxygen measurement equipment must increase as oxygen approaches ambient. This results in a loss of accuracy for open fireplaces with high air dilution ratios. This is reflected in the error bars for the AES in Figure 1. Tests 5 and 6, which are with doors closed (and hence less dilution) have much smaller error bars than tests 1 to 4. For example, Table 4 illustrates how a 0.1% absolute error in measuring oxygen concentration is reflected in g/kg PM value at 16% and at 20% stack oxygen.

Since US-EPA-M5G does not rely on oxygen values, it has a theoretical advantage over the other two methods at high dilution ratios, i.e., for open fireplace testing.

Table 4. Sensitivity to stack dilution, AES and OM41

Stack oxygen	Excess air factor (dilution)	Change in calculated PM value with 0.1% oxygen error
16%	4.3	4%
20%	23.2	13%

Table 5. Table of Test Results

	1	2	3	4	5	6
PM Factor, g/kg	Rumford open	Rumford open	Rumford open	Rumford open	Rosin door	Rosin door
OM41, actual		6.96	5.74	8.69	1.63	2.01
OM41 noleak					1.04	1.47
M7 equiv.		9.91	8.33	12.03	2.54	3.10
M7 equiv. noleak					1.64	2.12
AES	22 +/- 9.2	5.4 +/- 2.0	8.5 +/- 2.4	15.4 +/- 3.4	3.5 +/- 0.59	3.5 +/- .55
US-EPA-M5G	13.51	5.4	7.26	5.84	2.78	4.49
PM Rate, g/hr						
OM41		34.8	29.9	46.2	9.4	11.5
AES	39.9 +/- 17.1	10.4 +/- 3.9	8.2 +/- 2.4	54.6 +/- 12.6	9.2 +/- 1.6	12.4 +/- 2.1
US-EPA-M5G	18.2	10.7	13 19.7	19.8	7.3	16.0

Sensitivity to particulate weighing procedure

Both US-EPA-M5G and OM41 at McNear Brick involved weighing of filters and residues on site. The OM41 uses 6” filters and US-EPA-M5G uses 2” filters. The OM41 filter train can therefore handle a larger fraction of the flue flow. This is illustrated by a comparison of test 3-8-95-s2 (please refer to data appendix for test number cross-reference):

Table 6. Comparison of filter residue (catch) sensitivity (Rosin test 3-8-95-s2)

Test Method	Filter catch, grams	PM Factor g/kg	Filter catch for 1 g/kg PM factor
OM41	.0733	2.21	.0332
US-EPA-M5G	.00095	8.79	.0001

Given identical analytical balances, US-EPA-M5G has 300 times the sensitivity to weighing errors.

The McNear field tests took place in an unheated concrete building during a time of variable outside weather that included high winds and flooding. Two digital balances were used at McNear, one for US-EPA-M5G and one for the OM41. The US-EPA-M5G balance was mounted on a table, and the OM41 balance was mounted on concrete blocks in a heated chamber that was maintained at 40% relative humidity. Problems were encountered with the US-EPA-M5G balance, and it was replaced halfway through the tests. The balance was sensitive to table vibration, and there was heavy machinery operating nearby.

Effect of wood moisture

OM41 PM factor versus wood moisture data for all 10 Frisch Rosin tests is summarized in Figure 3. Correlation between PM factor and wood moisture for Frisch Rosin fireplace. Only OM41 data is available for all 10 tests. Although the absolute values for PM are in doubt due to a leak in the gas analyzer train, a constant leak would amount to a scaling error so that the relative PM rankings would remain the same. A PM minimum is evident in the 17 to 19% wood moisture range, with higher PM values for both drier and wetter wood outside this range.

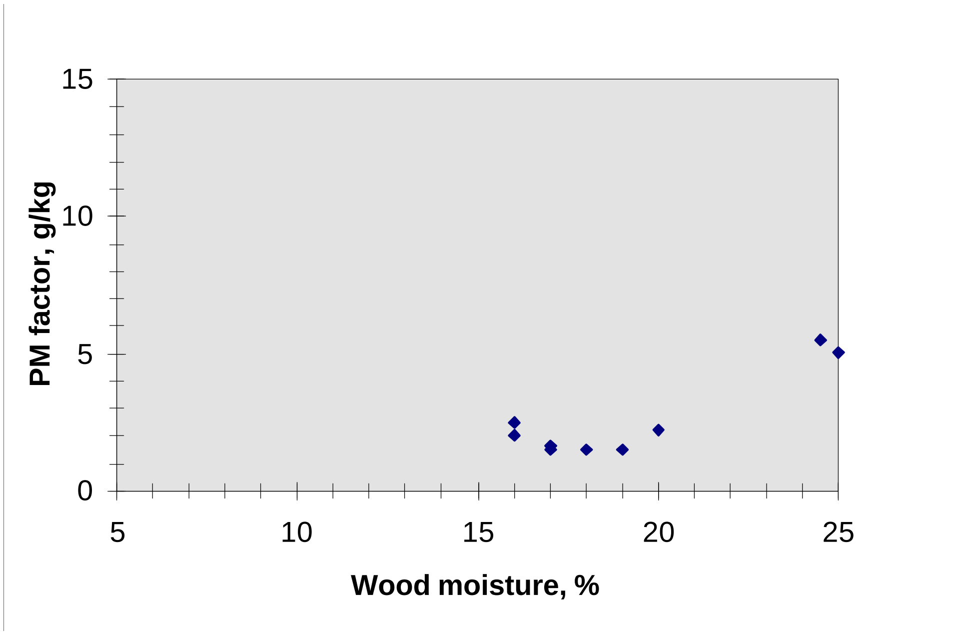

Figure 3. Correlation between PM factor and wood moisture for Frisch Rosin fireplace

EPA-M5G PM factor versus wood moisture data for the open fire Buckley Rumford tests is summarized in Figure 4

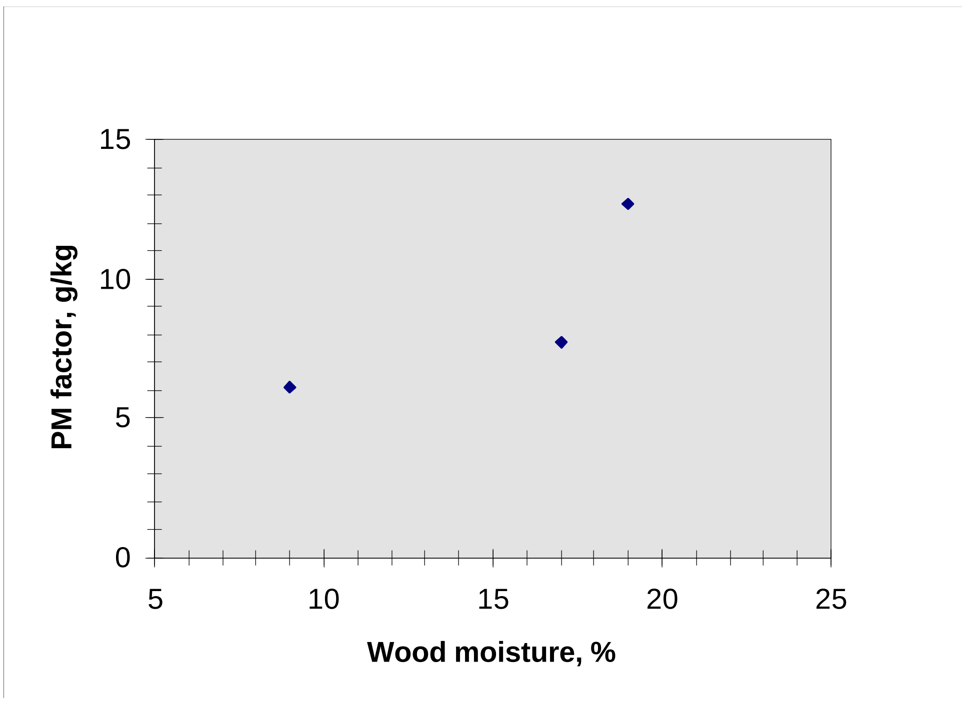

Figure 4. Correlation between PM factor and wood moisture for Buckley Rumford fireplace

CONCLUSIONS

Test method correlation

Five tests were run that compared all three methods. This is a small sample from which to draw definite conclusions. However, some general conclusions can be drawn, and some observations made about how the methods compare.

- On a subjective basis, the graphical summary in Figure 1 shows a reasonable amount of agreement between the three methods. This is encouraging, in view of some fundamental differences between the methods and the elusive nature of particulate emission measurement for residential wood combustion.
- When testing open fireplaces with high dilution ratios, methods that rely on oxygen to calculate stack mass flow are at a disadvantage. With the AES, this is clearly seen in the size of the error bars in Figure 1 for the open fireplace compared to the closed fireplace. This can be somewhat alleviated by calculating mass flow from CO and CO_2. An alternate mass balance calculation for the AES has been put forward on this basis. For OM41, oxygen is calculated from CO and CO_2, which amounts to a mass balance calculation.
- OM41 PM factor values appear to be consistently lower, particularly for the closed door tests where OM41 has more resolution. One possible factor may be the much shorter time between dilution, mixing and sampling with the short tunnel. This has been addressed in previous work (with high emission woodstoves) with an adjustment formula (M-7 equivalent.)[6]
- Burn rate determination is a problem. This results in different PM emission rate values for the same tests, depending on which definition of burn rate is used. Extending the defined burn time past the point at which the fire is out results in either a higher O_2 value for the AES or OM41, or in increased dilution for US-EPA-M5G.
- US-EPA-M5G appears to use a high tunnel dilution ratio and/or a low sample flow rate. Optimizing these would give less sensitivity to balance calibration error.
- Weighing filters in the field requires adequate environmental controls.

Fireplace emissions

- Actual emission values measured during this series of tests are in line with similar tests performed on substantially similar appliances at Lopez Labs[7].
- The Frisch combustion air setup for a fireplace with airtight doors appears capable, in and of itself, to substantially reduce PM emissions.

DISCUSSION

What was learned?

Exhaustive comparison testing was not within the scope of this project. However, the tests at McNear Brick yielded valuable information about the properties of different testing methods.

From a masonry industry perspective one of the main values was to have access, for the testing duration, to two recognized authorities on woodburning emissions testing, Dr. Dennis Jaasma from the Combustion Laboratory at Virginia Polytechnic Institute, and Paul Tiegs from OMNI Environmental Services Inc. This gave the masonry fireplace people present to ask detailed questions on their methodologies and gain valuable insights. It was a good opportunity to get the industry higher on the learning curve.

Need for tighter controls to yield more valid comparison data.

The 1995 California fireplace tests were a learning experience for all concerned. It is the first time that these three test methods have been run simultaneously in the field. In hindsight, a number of lessons were learned that could make future tests even more productive.

The OM41 data is in question because subsequent calibration at Lopez Labs revealed a leak due to a cracked filter housing. Using before and after comparison data from later Lopez tests suggests that this leak was present during the California tests. The leak would make the raw data err on the high side, because excess air would be reported as higher than actual due to extra oxygen in the sample line. The data in Table 7 gives values for both the raw and the adjusted data for the closed door tests. The correction factor would not be accurate at the higher air dilution ratios of the open fireplace tests and therefore has not been calculated. An M7 conversion factor for OM41 is also given[8]. M7 is the reference method to which US-EPA-M5G and other methods ultimately refer. An improved leak checking routine has been added to the OM41 procedure.

OM41 probably has the most robust method of avoiding weighing errors, particularly in the field. The large 6" filters allow for a higher catch fraction, and don't operate at the last digit of scale resolution, as the US-EPA-M5G filters do. A database has been developed for these filters and moisture sensitivities analyzed. A moisture correction routine has been developed using control filters, which lessens the effects of less-than-ideal field conditions.

A fireplace emissions database would be an asset to the masonry industry in future dealings with regulators. In comparing residential wood combustion particulate emission measuring methods, what is of real interest is how different time/temperature/dilution pathways affect resulting PM numbers and how they compare to reference methods. Therefore, it would probably make more sense in future comparison tests to use common equipment, such as laboratory balances, wherever feasible in order to reduce uncertainty in the comparison data. In the same vein, a consistent fueling protocol would increase the data quality.

Suggestions for future research

Replicate tests with additional controls

The comparison tests at McNear Brick were certainly not definitive nor, given limited resources, were they meant to be. In view of equipment problems with OM41 a repeat test is almost called for. Repeating the complete McNear series would no doubt yield a more solid database. Lessons learned from this first attempt could certainly be used to design a more robust future round of testing. It is noteworthy that, although EPA has ruled that "blind" field tests must be used to gain "equivalent to certified" status, consistency and controlled conditions are still needed if testing funds are to be spent wisely.

Pursue research into clean burning designs

A clean burning masonry fireplace has been demonstrated. Although somewhat peripheral to the present paper, it should be reported that the Frisch-Rosin fireplace underwent a 7 day certification test on the AES during the California testing. The AES is the only system to date that has undergone EPA auditing for masonry fireplace field testing. Results are given in Table 7, below:

Table 7. Certified AES test results for Frisch-Rosin

Parameter	Value

PM Emission Factor	2.2 g/kg
PM Emission Rate	2.9 g/hr
CO Emission Factor	44 g/kg
CO Emission Rate	59.7 g/hr
Net Delivered Efficiency	57.9%
Average Heat Output	15,184 BTU/hr
Average Burn Rate	1.33 dry kg/hr

These results are significant in view of the simplicity of the Frisch-Rosin design and air supply. It uses an external air supply consisting of 2 1" air tubes aimed directly at the fire. There is no air control, and the home owner does not have the opportunity to adjust the air. Although the exact configuration of the tubes is proprietary, the same principle could be researched for application to site-built fireplaces. A generic version of this air supply could be specified in building codes. In states such as Washington where fireplace doors have been mandated because of energy codes, open fireplaces are no longer an option. Once a glass door on a site-built masonry fireplace is accepted, it seems that there is a simple method to make it burn cleanly. The masonry industry should take note.

APPENDIX A:

Data Summary for Complete Test Series

DATE			06/03/95	07/03/95	07/03/95	08/03/95	09/03/95	09/03/95	10/03/95
RUN No.	OM41						BR-CMP1	BR-CMP2	BR-CMP3
	AES			discreet-1			discreet-2	discreet-3	discreet-4
	EPA-M5G			3-7-95-s1	3-7-95-s3	3-8-95-s3	3-9-95-s1	3-9-95-s2	3-10-95-s1
Rumford	**Data**		lc/g	tp	lg/g		presto	big cored wc	tp
	OM41	Wood Moisture					12.0	18.3	9.0
	AES			19			11.6	17.0	9.0
	OM41	Total Weight					22/22.4jf	22.9/23.9jf	23.4jf
	AES			11.24			22.4	23.8	21.1
	OM41	Number of Pieces					4	11	4
	OM41	Run Length					2.0	2.0	2.0
	AES			2.4			4.8	9.6	2.7
	EPA-M5G								
	OM41	Av. Stack Temp					267	162	208
	OM41	Av. O2%					20.15	20.10	20.12
	AES			20.1			19.90	19.80	19.40
	OM41	Stack Dilution Factor					27.98	25.97	26.92
	OM41	Burn Rate dry kg/hr					4.40	4.25	0.00
	AES			1.8			4.20	2.11	3.55
	OM41	g/kg CO					24.20	45.56	40.57
	AES			75.4				39.5 +/- 28.1	47.1 +/-18.88
	OM41	Combustion Effic, %					94.58	92.63	92.06
	AES	Combustion Effic, %		96.3			100.00	98.10	97.70
	OM41	Heat Trans. Effic, %					-8.01	47.27	24.07
	OM41	Overall Efficiency, %					-7.58	43.79	22.16
	OM41	g/kg OM41					6.96	5.74	8.69
	AES	g/kg AES		22.0 +/- 9.29			5.4 =/- 1.97	8.5 +/- 2.41	15.4 +/- 3.40
	EPA-M5G	g/kg M5	5.20	12.67	7.26	8.14	5.41	7.70	6.09

DATE			05/03/95	06/03/95	07/03/95	08/03/95	11/03/95	11/03/95	11/03/95	12/03/95	12/03/95	13/03/95
RUN No.	OM41		FR-DA	FRC-B	FR-DC	FR-DD	FR-DE	FR-DF	FRC-CMP4	FR-DG	FRC-H	FR-DI
	AES			wet wood	brick dust (M5)		discreet-5	discreet-6				
	EPA-M5G			3-6-95-s1	3-7-95-s2	3-8-95-s2	3-11-95-s1	3-11-95-s2				
Rosin	**Data**											
	OM41	Wood Moisture,%	24.5	25.0	19.0	20.0	17.0	16.0	17.0	16.0	17.0	18.0
	AES						-25.3					
	OM41	Total Weight, lbs	29.0	16.5	34.3	38.0	22.3	34.3	25.3	27.0	35.0	29.8
	AES											
	OM41	Number of Pieces	3	3	3	3	3	3	3	3	3	3
	OM41	Run Length, hrs	2.5	2	2	2	2	2	2	2	2	2
	AES											
	OM41	Av. Stack Temp, F	363	278	439	479	466	602	466	480	597	510
	OM41	Av. O2%	0.80	0.85	0.77	0.75	0.76	0.71	0.76	0.75	0.71	0.74
	AES											
	OM41	Stack Dilution Factor	7.86	11.05	5.69	5.95	7.94	6.67	7.94	9.72	6.50	8.23
	OM41	Burn Rate dry kg/hr	3.98	2.81	6.31	6.91	4.76	4.82	4.20	5.15	6.60	5.54
	AES											
	OM41	g/kg CO	96.65	80.29	48.75	55.41	51.99	40.56	52.00	64.37	43.51	46.96
	AES											
	OM41	Combustion Effic, %	86.93	88.97	93.89	92.87	93.48	94.63	93.48	91.74	94.48	94.11
	AES											
	OM41	Heat Trans. Effic, %	47.73	48.15	50.94	44.97	32.60	24.94	32.59	17.92	27.15	24.15
	OM41	Overall Efficiency, %	41.49	42.84	47.82	41.76	30.48	23.60	30.47	16.44	25.65	22.73
	OM41	g/kg OM41	5.51	5.03	1.52	2.21	1.63	2.01	1.63	2.50	1.52	1.48
	AES	g/kg AWS					3.5 +/- 0.59	3.5 +/- .55				
	EPA-M5G	g/kg M5		6.98	3.49	8.79	2.79	3.33				

REFERENCES

[1] D. R. Jaasma, J. W. Shelton and C. H. Stern, Final Report on Masonry Heater Emissions Test Method Development, Wood Heating Alliance, Washington, DC (1990).

[2] D. R. Jaasma, J. W. Shelton and C. H. Stern, Final Report on Fireplace Emissions Test Method Development, Wood Heating Alliance, Washington, DC (1990).

[3] S. G. Barnett, In-Home Evaluation of Emissions from Masonry Fireplaces and Heaters, Western States Clay Products Association, San Mateo, CA (1991).

[4] S. G. Barnett, Summary Report of the In-Home Performance of Five Commercially Available Masonry Heaters, OMNI 80132-01, prepared for the Masonry Heater Association of North America, Reston, VA (1992).

[5] U. S. Environmental Protection Agency, Standards of Performance for New Stationary Sources; New Residential Wood Heaters; Final Rule, 40 C.F.R. Part 60, Federal Register, 53(38), Washington, (1988), p. 5866

[6] U. S. Environmental Protection Agency, Standards of Performance for New Stationary Sources; New Residential Wood Heaters; Final Rule, 40 C.F.R. Part 60, Federal Register, 53(38), Washington, (1988)

[7] N. Senf, Very Low Emissions Cordwood Combustion in High Burn Rate Appliances - Early Results with Possible Implications, presented at the 88th Annual Meeting of the Air and Waste Management Association, San Antonio, (1995)

[8] S. G. Barnett, "Handbook for Measuring Woodstove Emissions and Efficiency Using the Condar (Oregon Method 41) Sampling System", Condar Co., (1985).