Low Emissions Residential Cordwood Combustion in High Mass Appliances - Recent Research and Results

Norbert Senf
Lopez Labs
RR 5
Shawville, Québec J0X 2Y0
email mheat@hookup.net

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ABSTRACT

Residential scale biomass combustion can contribute to the sustainability aspect of housing. It does not make sense to burn fossil fuel for low grade heat when a viable renewable energy alternative is close at hand in many areas of North America. In fact, further benefits result when sustainability principles also apply to cordwood harvesting. Sound forest management practice and large volumes of fuel harvesting can go hand in hand.

A number of obstacles exist in realizing the above scenario. The primary one is the atmospheric emissions associated with Residential Wood Heating (RWH). Particulate matter (PM) is the main concern. The range between best and worst technology can be two orders of magnitude. In fact, two orders of magnitude can separate PM performance of the same appliance at different combustion air settings, due to the presence of smoldering combustion at low burn rates. This is exacerbated by the fact that new housing is more efficient and hence the average heat load is in the low burn rate range for conventional woodstoves.

One promising solution to the above problem is to add heat storage to the appliance. This allows burn rates to be sufficiently high for clean combustion without a spike in the heat output rate. Simple and proven technology exists for this approach in the form of masonry heating systems. These are traditional appliances in many of the colder regions of the world where the idea of hearth (literally "heart") is deeply embedded in the concept of what constitutes appropriate human shelter.

Combustion research into RWH has only started since the 1973 oil embargo. Due to the extremely complex nature of wood combustion, the body of useful results to date is meager compared to other fields and many questions remain. With the support of the small, dedicated community of masonry heater builders, the author and colleague J. Frisch established Lopez Labs in 1992 to enable research into specific aspects of masonry heater and masonry fireplace combustion. Sound research methodologies have evolved, and a statistically significant database of test results is emerging as a result. Improved construction practices for both masonry heaters and masonry fireplaces have resulted.

The complex nature of wood combustion makes experimental repeatability difficult, particularly in an in-home test situation. As a result, much data from prior work is incompatible with current methods. European data, for example, is difficult to translate into a North American context. Definitions for emissions and efficiency vary, as do testing protocols.

The most recent involvement by Lopez Labs has been in a comparison field test of three different PM emissions measuring test methods. Validating low cost testing methods remains a priority.

A novel and somewhat unexpected result has been the development of a simple combustion air supply for a conventional masonry fireplace that resulted in an order of magnitude PM emission reduction in a certified test.

In the author's opinion it is erroneous to assume that the concept of a traditional woodburning hearth is outdated and incompatible with current trends in housing technology. In fact, it may be a pointer towards more environmentally appropriate technologies and practices in other sectors as well. RWH emissions research must be integrated into the larger context of sustainability.

INTRODUCTION

Household scale biomass combustion, or residential wood heating (RWH) can contribute to the sustainability aspect of housing. It does not make sense to burn fossil fuel for low grade heat when a viable renewable energy alternative is close at hand in many areas of Canada and the United States. Further benefits result when sustainability principles also apply to cordwood harvesting[1].

RWH emissions are major contributors to degraded air quality in a number of sensitive airsheds that have significant numbers of woodstoves and fireplaces[2]. Improving the emissions performance of RWH is the main requirement before significantly increased use of this technology can occur.

Conventional woodstoves have a critical burn rate, the point at which flaming combustion changes into smoldering combustion. Emission ratios as high as 100:1 can be observed on either side of this line. This can present a serious problem in new efficient housing with low average heating loads, and is the focus of most current combustion research for this appliance type.

This paper deals with recent combustion research for another appliance type, high mass masonry heaters and fireplaces. Masonry heaters are able to use a thermal mass to store heat for later release. This makes them essentially burn rate independent and thereby able to consistently achieve low emissions in field testing, regardless of heat output.

Masonry fireplaces, on the other hand, would be major sources of air pollution if not for the fact that they are used infrequently[3,4]. An unexpected result of recent research by the author and colleague J. Frisch was the development of a simple combustion air supply that is able to reduce emissions from conventional masonry fireplaces to below levels specified in the US-EPA regulation for woodstoves.

RESIDENTIAL WOOD HEATING ISSUES

Emissions

Sulfur

It is interesting to note that wood is essentially a clean fuel, with almost no sulfur content to speak of.

Carbon monoxide

Carbon monoxide (CO), like all woodburning emissions except fly ash, is a product of incomplete combustion. Because CO is relatively easy to measure, CO emissions have been used as a surrogate measure of overall woodburning emissions in Europe, where regulations have until recently focused exclusively on CO.

Particulates

This is not the case in North America, however. American data indicates that woodsmoke-caused wintertime violations of National Ambient Air Quality Standards (NAAQS) tend to occur earlier and more often from particulate matter (PM) than CO.

PM has become the focus of emissions research and regulation in the United States[5] and Canada[6]. The greatest public health concern is from particulate matter that is smaller than 10 microns (PM10). Particles of this size can pass directly into the bloodstream through the lung walls.

PM is a complex and variable mixture of incomplete combustion products. At the low toxicity end of the scale are non soluble inorganic compounds. These include soot, which is pure carbon, and ash, which consists of mineral salts. A 1992 American study[7] of in-home emissions from a masonry heater found a PM non soluble fraction of 61%.

The semi-volatile soluble organic compounds cool upon exposure to the atmosphere and condense into a very fine mist of chemically complex tar droplets, with 90% of the particles smaller than 1 micron. Of the soluble organic compounds, of most concern are the polycyclic aromatic hydrocarbons (PAH’s), many of which are Class A carcinogens[8].

PM as defined by US-EPA-M5G and US-EPA-M5H is unclassified as to size or chemical analysis. A comparison of PM emission factors for different appliances as tested in the field is given in Table 1. Emission factors are expressed in terms of grams of PM emitted per dry kilogram of fuel burned.

Table 1. Comparison of US-EPA field tested emissions by RWH appliance type[9]

RWC Appliance Type	PM emission factor, g/kg
Masonry fireplaces	17.3
Masonry heaters	2.8
Woodstoves (non-catalytic)	
Pre-EPA	15.3
EPA Phase II certified	7.3
Pellet Stoves	
Uncertified	4.4
EPA Phase II certified	2.1

A 1986 Austrian laboratory study[10] comparing emissions from a masonry heater and a conventional woodstove operating at a high burn rate found average PAH emissions from the masonry heater to be 20 $\mu g/m^3$, compared to 2000 $\mu g/m^3$ from the woodstove. U.S. data from field studies[11] indicates an average PAH emission level for US-EPA certified woodstoves under all combustion conditions of 0.250 g/kg. Assuming 300% excess air, this is equivalent to 15,000 $\mu g/m^3$.

Volatile organic compounds

Little data is available on volatile organic compounds (VOC's). The American study cited above found VOC emissions of 0.4 g/kg from a masonry heater.

RWH Sustainability Issues

Introduction

It is important to place RWH issues into an appropriate context. If we merely compare RWH PM and CO emissions numbers with those for oil and gas, our focus will be too narrow. While oil and gas PM and CO emissions are lower, a more meaningful comparison will include total environmental impacts. This in no way is meant to excuse inappropriate RWH use or the use of outdated technology or practices that result in higher emissions than necessary. Burning cordwood is a complex process and it is not unreasonable to place some demands on the user in order to realize potential environmental advantages. Our transition to a sustainable future will require user involvement.

Greenhouse gas emissions

Wood is not a fossil fuel. Its use does not result in the introduction into the atmosphere of otherwise permanently sequestered carbon, as the use of fossil fuels does. Neither Canada nor the United States have to date demonstrated any serious commitment to reducing greenhouse gas emissions, and in fact Canada has already announced that it will default on the lax commitment it made at the UN Framework Conference on Climate Change in Rio. Serious current estimates of the fossil fuel consumption reductions required by Canada and the United States range up to 75%[12]. Obvious solutions such as RWH should not be ignored by the scientific community. Although difficult to do on a large scale, it is nevertheless much easier to replace home heating fossil fuel use with renewables than to replace transportation fossil fuel use, due to the lower energy quality (entropy) requirements for home heating. It can be argued that using low entropy fossil fuel merely to produce low grade heat is unsustainable by definition.

Sustainable forest management

Wood fuel can provide a means of living off annual solar income, which is a key component of most proposed strategies for attaining sustainability[13]. The entire fuel cycle, including forest management, must be addressed. A recent study of the potential for a firewood industry in Renfrew county, Ontario[14], concluded that adding firewood to the harvesting mix could in fact bring many marginal woodlot operations to a point of profitability. Interestingly, one of the main obstacles to implementing this change was seen as a cultural one in the logging community: “Real men don’t cut firewood. Real men cut trees!”

A second example is provided by Germany, where tremendous amounts of firewood are generated. German firewood consumers are offered the option of purchasing fuel that comes from certified sustainable forestry operations. Because these forestry management systems are more labour intensive there is a secondary benefit of increased forestry sector employment.

Regulatory and Testing Background[15]

The 1988 US-EPA woodstove regulation quickly became a benchmark. It defined emissions testing for domestic wood-burning appliances, where previously several proposed testing standards were in the running. PM as defined operationally by US-EPA-M5H and US-EPA-M5G is now the research focus for anyone wanting to manufacture and sell woodstoves in the United States. At the same time, woodstoves were defined rather narrowly to exclude fireplaces, masonry heaters, cookstoves and furnaces from the regulation.

An immediate problem arose when Masonry Heater Association (MHA) members negotiated an exemption for clean burning masonry heaters with the Washington State Department of Ecology. There was no US-EPA compatible PM emission data for masonry heaters. The bigger challenge however, was that in 1988 there was no recognized test method for measuring PM emissions in either masonry heaters or masonry fireplaces[16].

A joint industry project resulted in work towards developing a laboratory testing protocol for masonry heaters and masonry fireplaces at Shelton Research and Virginia Polytechnic Institute (VPI)[17,18].

Subsequently, a field study of masonry fireplace and masonry heater emissions was conducted by OMNI Environmental Services, a US-EPA accredited laboratory, under industry sponsorship[19].

MASONRY APPLIANCE PERFORMANCE TESTING AT LOPEZ LABS

Background

Lopez Labs was the outgrowth of MHA efforts to address regulatory issues, and was established by the author and colleague J. Frisch in 1992. A performance testing program on a number of different high mass appliances was carried out over a period of four years[20].

Recent Testing and Results

Fueling protocol

Experience gained from the original masonry fireplace tests at Virginia Polytechnic with dimensioned lumber led to the conclusion that Douglas Fir cordwood should be the fuel of choice for field testing to avoid having to correlate the two fuels. Experience with cordwood at Lopez Labs over four years of fireplace and masonry heater testing has resulted in the development of a Lopez Labs fueling protocol. Rather than being a fixed fueling method, it is a specification for documenting the fuel charge in enough detail to allow the initial firebox condition to be reconstructed at a later date.

Masonry heaters

Selected data for Lopez Labs masonry heater tests from 1993 to 1995 are presented below:

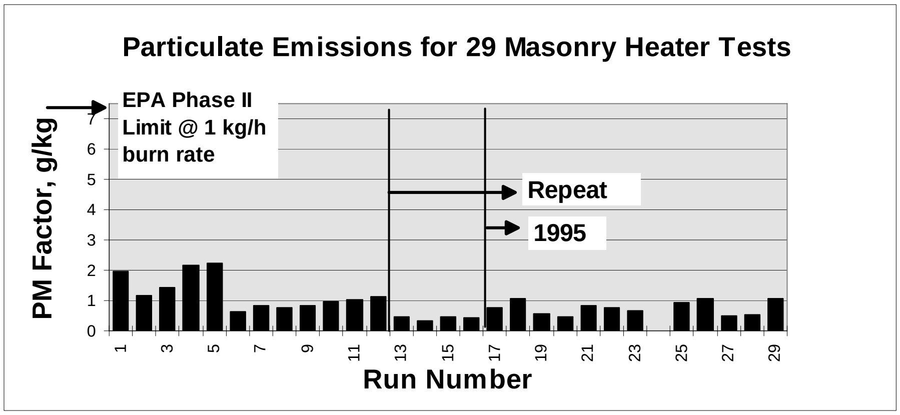

Figure 1. Lopez Labs 2 yr. test results on one masonry heater

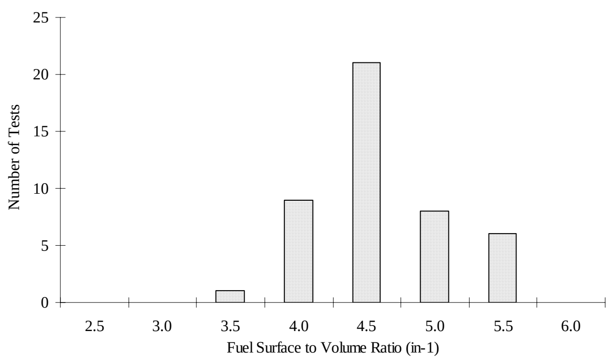

Figure 2. Distribution of average fuel sizing ratio for 45 masonry heater tests.

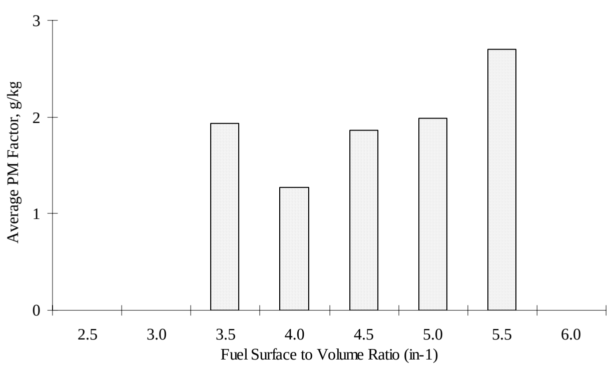

Figure 3. Distribution of PM emission factor by fuel sizing ratio for 46 masonry heater tests.

Masonry fireplaces

A series of tests was conducted at Lopez Labs in 1993 on a Frisch Rosin masonry fireplace using conventional glass doors and a conventional combustion air supply.

In 1994 a series of fireplace tests was conducted on a Frisch Rosin masonry fireplace using a new combustion air supply. The conventional “cowbell” combustion air inlet on either sidewall was replaced by a length of 1.5” i.d. steel tubing, aimed directly at the fire.

Table 2 compares the results from the standard air supply in 1993 with the modified air supply in 1994. In addition to a large particulate emissions reduction, the most obvious change observed was in excess air, which was reduced from 1000% to 410%. Qualitatively, this was observed as a “blowtorch” effect with the new air supply. With an airtight door, all of the chimney pressure is available at the firebox combustion air inlet to maximize the velocity of combustion air at the inlet opening. Less air is able to bypass the combustion process, resulting in a higher burn rate and higher stack pressure. A conventional fireplace lacks a heat exchanger, and therefore a higher burn rate, assuming equivalent excess air, results immediately in higher stack temperature. Stack temperature and burn rate become coupled by the combustion air.

Further testing indicated that the nozzle could be reduced to the point of creating a “normal” looking fire without a significant PM penalty.

Table 2. Summary of 1993 and 1994 Lopez Labs masonry fireplace tests

Data Source, by Appliance Type	Particulates, g/kg	Carbon Monoxide, g/kg	Net Efficiency %
Rosin fireplace w. airtight door - conventional air supply.(16 tests, cold start)	8.1	55	26
Frisch Rosin fireplace w. airtight door - high velocity air supply (8 tests, hot start)	2.7	39	55
Frisch Rosin fireplace w. airtight door - high velocity air supply (2 tests, cold start)	1.4	47	52

A COMPARISON OF EMISSIONS MEASURING METHODS

Introduction

In 1995, Western States Clay Products Association (WSCPA) sponsored a series of field tests of 2 masonry fireplaces[21]. The tests were conducted at the McNear Brick Company in San Rafael, CA. Three emissions measuring methods were used simultaneously– US-EPA-M5G; the Automated Emissions Sampler (AES), developed by OMNI Environmental; and Oregon Method 41 (OM41) as modified for use at Lopez Labs..

Fireplaces Tested

Frisch Rosin

This fireplace was identical to the one used for the 1994 Lopez Labs fireplace test series.

Buckley Rumford.

The Buckley Rumford uses the traditional Rumford fireplace design. A 30” Buckley Rumford with 18’ of 8x12 flue was used for the McNear tests.

Test Description

Frisch Rosin

Prior to the tests at McNear Brick, 26 tests spread over two years were performed on the Rosin fireplace at Lopez Labs using OM41. A total of 10 tests were performed at McNear Brick. There is OM41 data for all 10 tests, US-EPA-M5G data for 5 tests, and data from all three methods for 2 tests. In addition, a second AES system was run in normal (non-discrete) mode for a 7 day certification run. Results from this certification test are reported in Table 3.

Subsequent to the McNear tests an additional 9 tests were conducted 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

A total of 7 test runs were done at McNear Brick. All runs were in the open fireplace mode. All three test methods were used for three tests, US-EPA-M5G only was used for three tests, and for one test there is US-EPA-M5G and AES data. Fueling for the tests was variable, and on some tests included the use of a gas log lighter.

Test Results

Test results for the 6 comparison tests are summarized in Figure 4. Tests 1 – 4 are on the open Buckley Rumford and tests 5 – 6 are on the closed Frisch Rosin. The difference between open and closed combustion is readily apparent. PM emission values for the closed tests are lower, and clustering of the data points is noticeably tighter due to less dilution air.

Figure 5 gives the correlation between wood moisture and OM41 PM values for the Frisch Rosin fireplace.

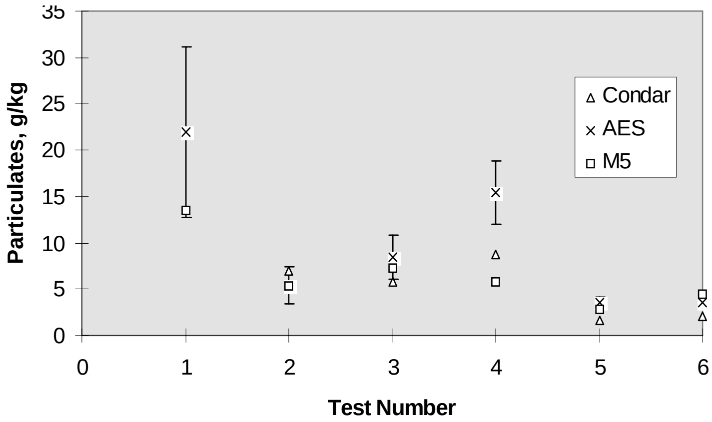

Figure 4. Fireplace PM emission factor, comparison of three test methods.

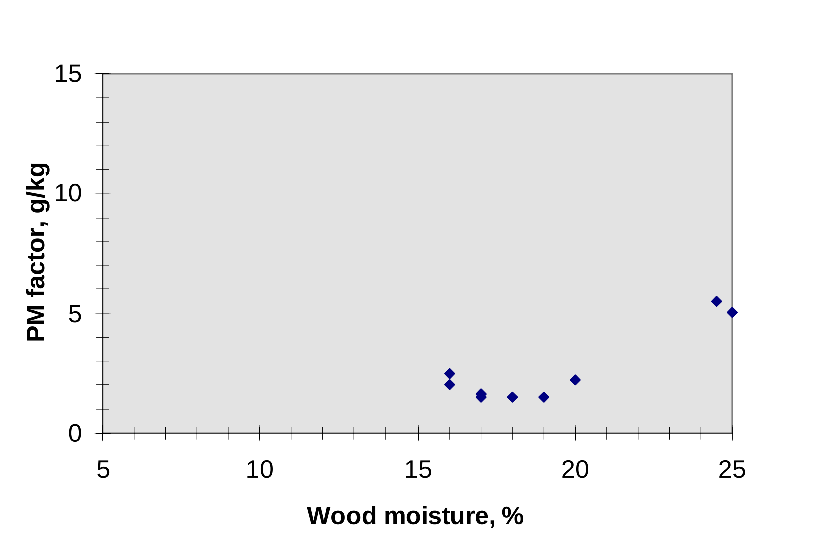

Figure 5. Correlation between PM factor and wood moisture for Frisch Rosin fireplace

Table 3. Certified AES test results for Frisch Rosin fireplace

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

CONCLUSIONS

Masonry heaters are able to burn cordwood in-home with PM emissions that are significantly lower than those of certified woodstoves.

The difference in emission levels of the most toxic emissions (PAH's) between masonry heaters and woodstoves may be two to three orders of magnitude.

Simple new technology for clean burning masonry fireplaces has been developed and demonstrated.

DISCUSSION

There is a general association of RWH with atmospheric pollution in the eyes of the public and the scientific community. It is important to create awareness of new clean burning technology such as high mass appliances.

The AES certification test results for the Frisch Rosin with the Frisch air supply are noteworthy. While it is only a single data point due to the cumulative nature of the AES method, it is in good agreement with Lopez Labs data. Data from this testing allows us to predict with more confidence the possibility of a clean burning site built masonry fireplace. A likely path will be to provide a trained fireplace builder with a specification for airtight ceramic glass doors and combustion air inlet configuration. For the end user, it may require a specification for fueling and operating parameters.

High mass RWH technology demands serious consideration as a component of sustainable housing.

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