Development of a Fireplace Baseline Particulate Emission Factor Database

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ABSTRCT

A review was conducted of all available fireplace particulate emissions test reports and publications in order to develop a fireplace particulate emissions database. This project was done to provide baseline emissions levels to an ASTM committee developing an emissions test method for factory-built fireplaces. These data also provide improved information for emissions inventory development as compared to the AP-42 fireplace particulate emission factor. The AP-42 fireplace particulate emission factor is based on only four studies and it's database is dated, as two of the studies were conducted in the 1970s and two in the early 1990s. Most of the appliances tested in the four studies were site-built, masonry fireplaces; there were only three factory-built fireplaces tested in these four studies. In the last decade, roughly 650,000 wood-burning factory-built fireplaces have been installed annually in U.S. new home construction. Consequently, factory-built fireplaces now represent the majority of fireplaces in U.S. homes. Additionally, 24 of the 54 tests included in the four studies, used to develop the AP-42 value, were from a single 1990 study, which had higher values than typically reported in the other studies.

The database developed and reported here was from 34 [ref. 1-34] studies, which included pertinent fireplace emissions data, and represents 360 test runs. The resulting database shows that the 17.3 g/kg AP-42 value is approximately 33% high.

With roughly 28 million wood-burning fireplaces (without inserts) in the U.S., as of the end of 2003, a change in wood-burning fireplace emission factors could have a significant effect on emission inventories. To provide additional insight we have divided the data into several categories: (1) masonry and factory-built fireplaces, (2) cordwood and dimensional lumber and (3) fireplace doors open and closed.

INTRODUCTION

The emissions from fireplaces are becoming increasingly important. Wood-burning fireplaces are being installed into U.S. homes at a rate of about 650,000 per year. The total number of fireplaces sold annually is on the order of six times the number of wood heaters (wood stoves, inserts and freestanding fireplaces). Moreover, most new fireplaces are associated with new home construction, whereas many wood stoves are sold as replacements of older models. State and local air quality managers are looking for ways to lower $PM_{2.5}$ in response to the new federal standards. Fireplace emissions are largely unregulated at this time and the technology to reduce $PM_{2.5}$ emissions from them is unproven or impractical, additionally, a standard test method to measure emissions has not yet been developed. Because of the increased importance in fireplace emissions it is foreseeable in the future that fireplaces will be regulated nationwide and a test protocol will be developed to document emissions from them. An ASTM committee is drafting a test method that could be adopted by the EPA or other regulatory agencies.

This database was developed in order to provide fireplace baseline data to that ASTM committee. It is important that the test method under development reflect emissions from real world use of fireplaces. The hearth industry learned from the wood stove NSPS process that a test method that produced values that do not reflect real world values is a consistent problem for emission inventory development. Therefore, there was particular focus on emissions results of factory-built fireplaces burning cordwood, which is the most common in-home fireplace use scenario.

LITERATURE REVIEW AND DATA COMPILATION

Of the available sources of data on fireplace particulate tests in OMNI's archive, 34 sources of data were used. Some of the tests reviewed collected sample over only parts of fires, some tests used novel test methods or used research appliances, etc. We used our best professional judgment when removing runs from the database or when averaging multiple samples collected over single burns. Some of the test reports had very little supporting documentation; in a few cases to convert results in g/hr to g/kg, when the burn rate was not reported, the average burn rate for the database was used (4.8 kg/hr).

There are four main sampling methods utilized in fireplace emissions testing. They are: EPA Method 5, EPA Method 5G, EPA Method 5H and the ESS/AWES sampling systems. EPA Method 5 collects sample at a rate proportional to exhaust flow, directly from the flue exhaust and historically included only the particulate caught on a heated filter, this method does not include the condensable portion of the emissions, in order to represent total emissions a "conversion" factor has been developed. EPA Method 5G involves a large dilution tunnel run at a constant rate, which collects all of the exhaust from an appliance and mixes it with ambient air. This method cools the exhaust stream, the condensable portion of the emissions form particles and the total particulate mass is collected on an ambient temperature filter. This method was designed to collect particles in the form that they will be in once they enter the atmosphere. EPA Method 5H collects sample from inside the flue exhaust at a rate proportional to exhaust flow, as does Method 5, but includes cooled impingers and a "back half" filter after the front filter to collect the condensable portion of the emissions, which Method 5 failed to collect. The results from testing with EPA Method 5H have become the standard format for regulations and emission calculations. For this reason the other three test methods have conversion factors to convert them into Method 5H equivalents. The ESS method, designed for the Washington State Fireplace Test Method (WAC 51-40-31200), and the AWES sampling systems [described in three publications – ref. 35,36,37] were both designed to be "in-home" samplers. Once an appliance is installed into a residence, it is difficult to test by the previously mentioned EPA test methods. The ESS/AWES systems utilize a heated front filter and cooled canisters of XAD-2 resign designed to collect condensable emissions. The methods sample at a constant rate throughout the test. All of these test methods use dimensional lumber, as opposed to cordwood, as the fuel. This is done to create fires that are reproducible and consistent.

EPA Methods 5, 5G and 5H and associated wood heater operational Method 28 can be found in 40CFR Part 60 but were not designed for fireplace testing; Methods 5G, 5H and 28 were designed for wood heater testing, while Method 5 was designed for industrial smoke stack testing. In order to use any of the three EPA methods for fireplace testing significant modifications have to be made. Because there is no standard test method for fireplaces, different modifications to the EPA methods were been made in different studies. This causes difficulty in comparing one study to the next and when converting values into EPA Method 5H equivalent values. Due to the variability in test methods all the studies in this database, which were based on the EPA methods, were grouped together into three categories, Method 5 like, Method 5G like and Method 5H like.

For this database the conversion factors used were:

EPA Method 5 to EPA Method 5H equivalent

EPA Method 5H equivalent = EPA Method 5 / 0.89 [ref. 24]

EPA Method 5G to EPA Method 5H equivalent (g/hr)

EPA Method 5H equivalent = 1.619 * $(M5G)^{0.905}$ [ref. 38, 39]

AWES to EPA Method 5G equivalent (g/hr)

EPA Method 5G equivalent = 0.8635 * $(AWES)^{0.9288}$ [ref. 38, 39]

ESS to EPA Method 5H equivalent (g/kg)

EPA Method 5H equivalent = 1.254 + (0.302 * ESS) + $(1.261*10^{-ESSA})$ [ref. 40]

RESULTS

Table 1 is a summary of the key findings. For comparison to the database developed here, OMNI attempted to recreate the original database that produced the values listed in AP-42. OMNI was unable to repeat the exact values using the same data as was used by the EPA.

Figures 1-6 are histograms of the emission results, in both Method 5H and Method 5G equivalence, for the three key categories: (1) all of the tests, (2) all cordwood tests and (3) all factory-built, cordwood tests.

Table 1
Database Summary of Particulate Emission Factors for Masonry and Factory-Built Fireplaces

Parameter	5G g/kg		5H g/kg		Count
	Mean	Median	Mean	Median	n
All masonry and factory-built (zero clearance)	8.4	6.4	9.5	7.5	360
All cordwood	11.7	11.3	13.0	12.6	167
All dimensional lumber	5.6	4.3	6.5	5.2	193
All with closed doors	4.8	3.5	5.6	4.4	104
All with open doors	9.9	8.4	11.1	9.8	256
All masonry fireplaces	9.6	7.2	10.6	8.7	90
All factory-built fireplaces	8.0	6.1	9.2	7.2	270
Cordwood, factory-built, open doors	12.4	11.9	13.9	13.5	92
Dimensional lumber, factory-built, open doors	7.1	5.6	8.2	6.5	92
AP-42 calculated from referenced tests*	15.2	14.5	16.4	15.9	54
AP-42	16.2	-	17.3	-	-

Notes: Three outlier runs were removed from the database, average moisture for all runs was 20% and average burn rate for all runs was 4.8 kg/hr.
*OMNI was unable to duplicate the exact AP-42 values from the tests cited.

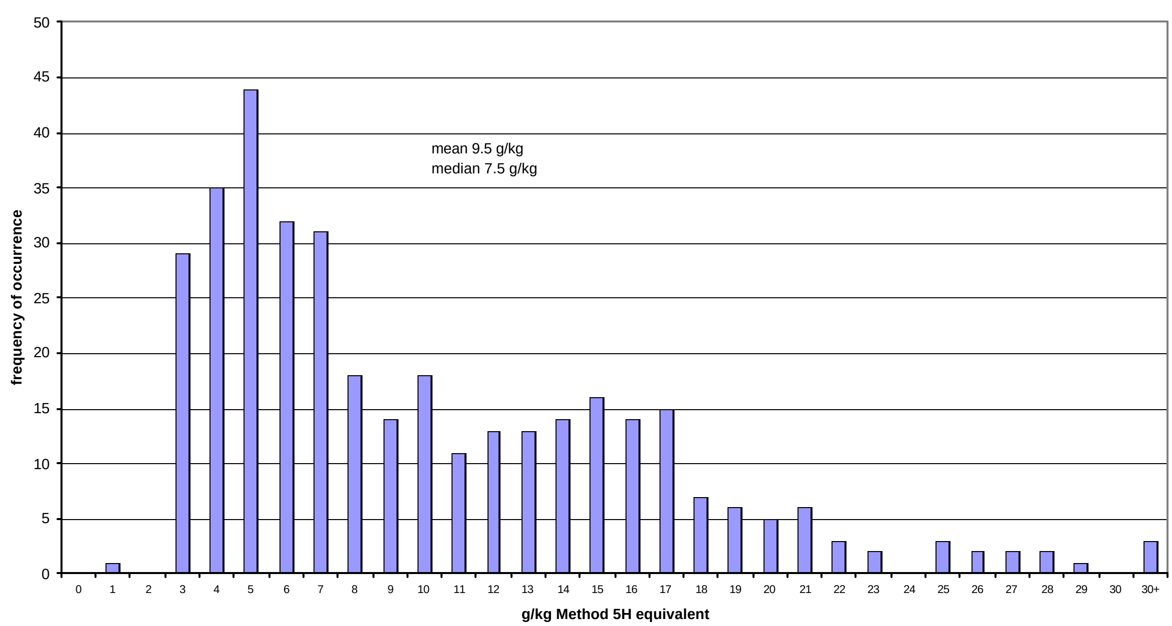

Figure 1 Distribution of Emissions – Data from All Tests, 5H equivalent

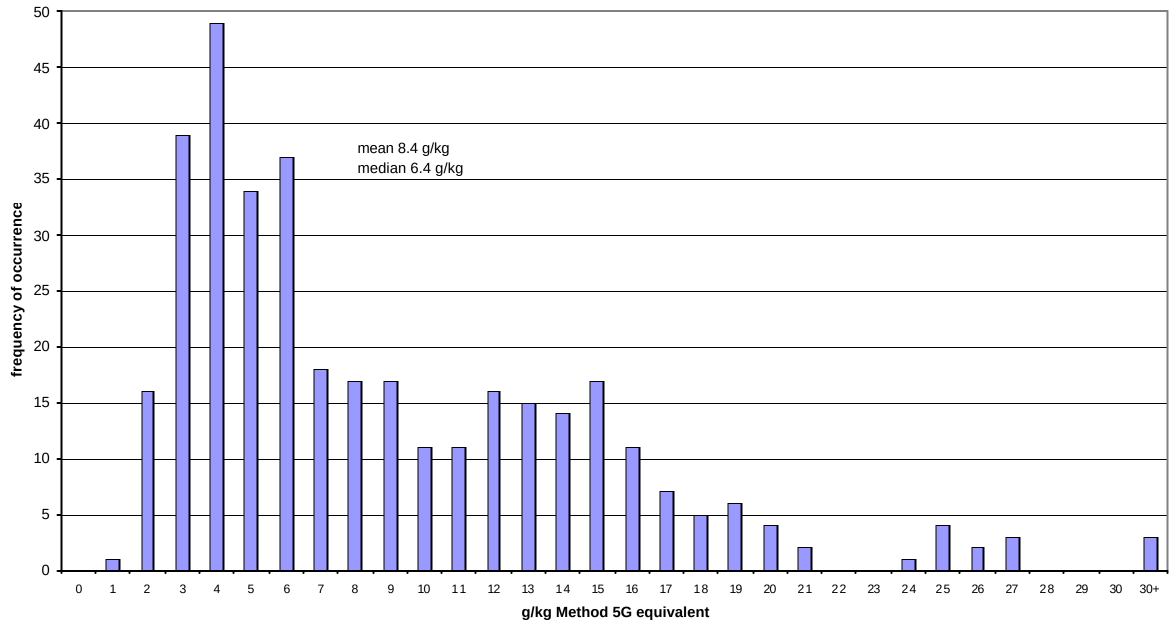

Figure 2 Distribution of Emissions – Data from All Tests, 5G equivalent

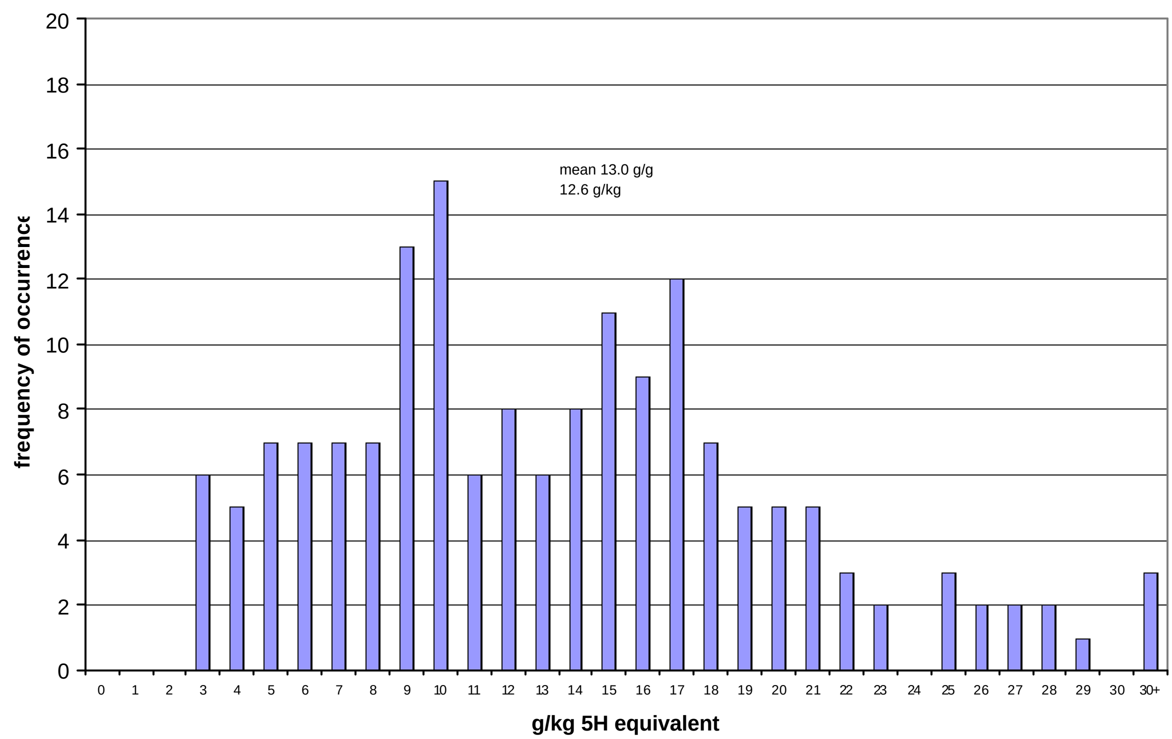

Figure 3 Distribution of Emissions – Data from Only Cordwood Tests, 5H equivalent

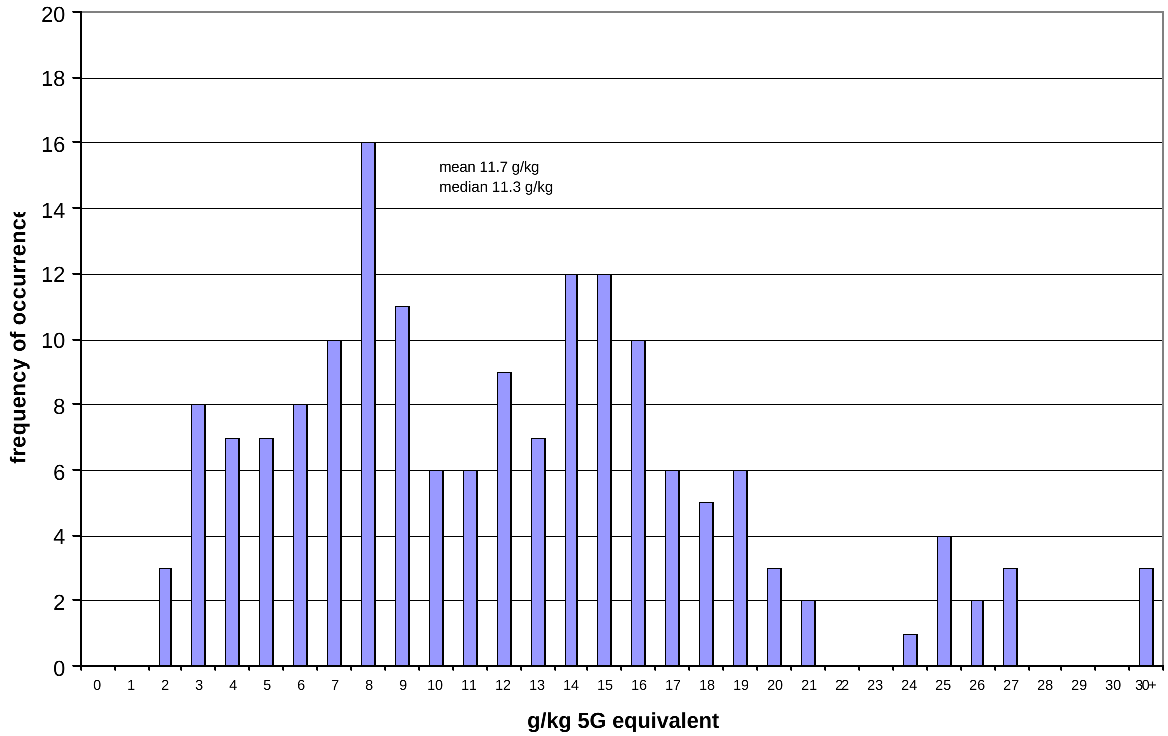

Figure 4 Distribution of Emissions – Data from Only Cordwood Tests, 5G equivalent

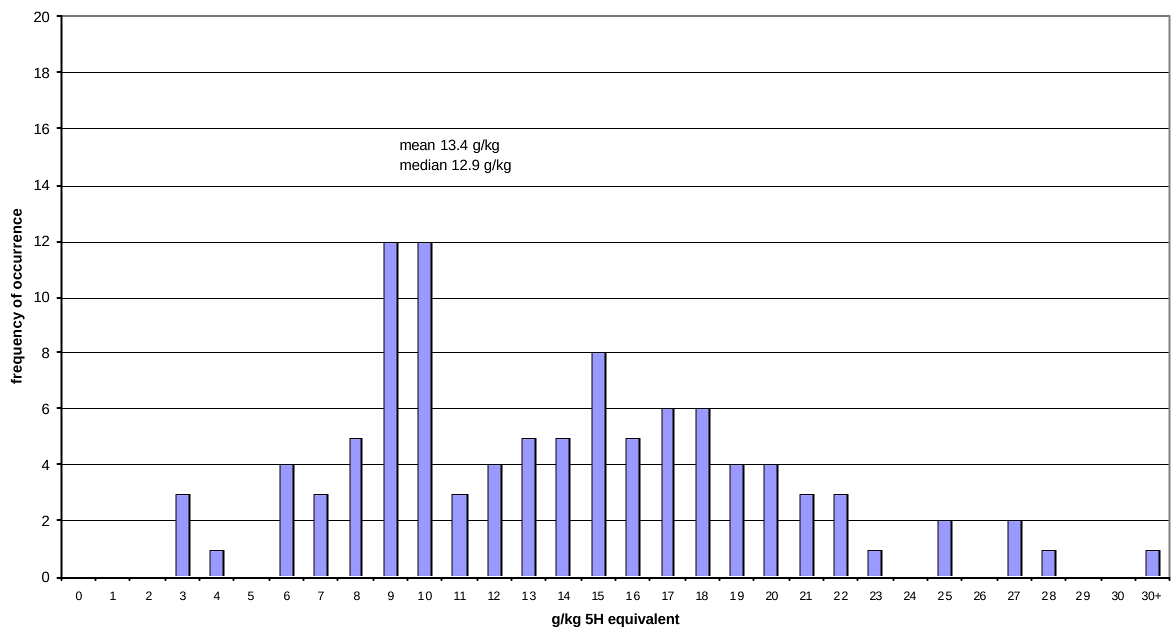

Figure 5 Distribution of Emissions – Data from Factory-Built, Cordwood Tests, 5H equivalent

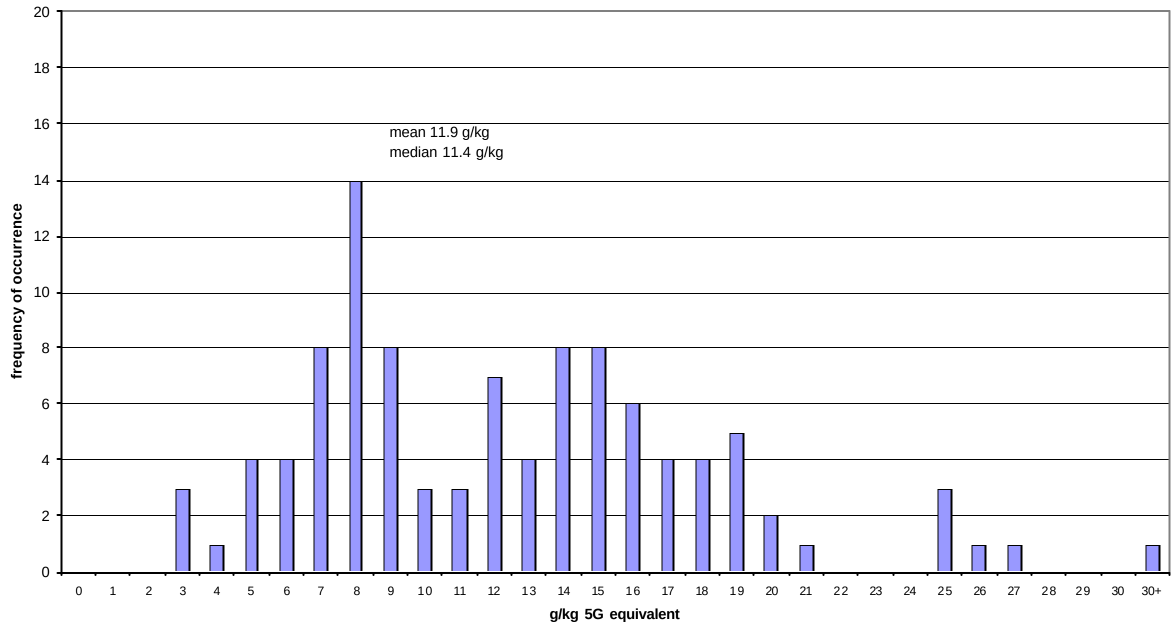

Figure 6 Distribution of Emissions – Data from Factory-built, Cordwood Tests, 5G equivalent

CONCLUSIONS

The average emissions from the database for all fireplaces, burning all wood types, are 9.5 g/kg 5H equivalent, 8.4 g/kg 5G equivalent.

The average emissions from all factory-built fireplaces, burning cordwood with open doors, which is the category most relevant to the ASTM committee, are 13.5 g/kg 5H equivalent, 12.4 g/kg 5G.

AP-42 is 33% higher than suggested by this database.

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