

Content and emission characteristics of Artificial Wax Firelogs

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Abstract: Information^{1,7} found regarding these products was fairly old with very few independent studies to measuring the emissions. Environment Canada and the EPA (Region 5) collaborated in this study to analyze the contents of 5 types of wax firelogs and measure their emission characteristics. OMNI Labs was contracted to conduct the study, under the direction of James Houck. Most of the logs were manufactured by the two major producers of these products,

The results of the study indicate that the wax used for these products had a high oil content. The results from the study indicate significant variations of metal content between the logs. This may be attributed to the wax and source of the wood fiber.

The emission data indicated that the levels of particulate and chemicals such as PAHs are less than burning with cordwood but provided some interesting comparisons.

This paper will describe the burning characteristics and emissions created from these logs and provide an update of the contents which can be expected when using these products.

Introduction: This study was done to find out the current emissions from burning these wax fire logs and their composition. The information on these products was fairly old and some funded by the companies. There were very few independent studies describing the composition of these products as well. The purpose of this study was to get the composition information and measure the emissions from these products. OMNI Labs was chosen for the study because of their extensive experience and research done with products of this kind. Dr. James Houck, has done studies on these types of products as well. We hope the information obtained from this study will provide us with an update of the type of materials used in these logs and the quantity and quality of the emissions from them during the burning cycle.

Test program:

The test logs were gathered from a number of major retail Ontario stores as well as an American retail store. It was important to obtain logs made in Canada and US for the test to identify any differences in logs produced in different locations. We decided to test one non-wood/wax firelog as this product is available in most retail stores along side of the wax/wood firelogs. The product is a firelog made of coffee grounds. The log types and sizes used for this study were:

Java Log, 2.3 kg. (5 lb.), made of coffee grounds and wax by Robustion Technologies Inc., in Ottawa , Canada

Northland, 1.4 kg. (3 lb.) firelog made of wood and wax by Conros Corporation, in Canada

Pine Mountain Superlog, 2.7 kg. (6 lb.) firelog made of wood fiber and wax by Conros Corporation, in Canada

Easy Time Firelog, 2.3 kg. (5 lb.) firelog made of wood fiber and wax by Duraflame, Inc., in Canada

Xtra Time Firelog, 2.7 kg. (6 lb.) firelog made of wood fiber and wax by Duraflame, Inc., in the U.S. (Kentucky).

All tests were conducted in a 36-inch zero clearance radiant fireplace with open glass doors. The exhaust from the burning logs were measured and collected in a 36 cm (14 inch) dilution tunnel. Each test consisted of burning two firelogs, one at a time as per manufacturer's instructions. The second firelog was started after the first firelog's flame went out. Emissions were sampled until the interior chimney temperature, 30 cm. (1ft.) above the fireplace, was 5.6°C (10°F) above the indoor laboratory temperature.

The dilution tunnel was used to treat the fireplace emissions to provide a representative characteristic of the emission as they exit the chimney and mix with the ambient air.

Sampling and Test Methods⁶:

Air Emissions

Pollutant samples were collected from a dilution tunnel and analyzed following standard sampling and analytical methods.

Particulate samples were collected isokinetically onto Gelman type A/E filters and processed following the protocols specified for wood heaters (40 CFR Pt. 60, App. A, Method 5G) in OMNI's EPA accredited wood heater testing laboratory (certified under 40 CFR Subpart AAA, Pt. 60). The total particulate values were the sum of the mass of material collected on the filter and the material removed from the filter holder and buttonhook nozzle with an acetone rinse. The PM_{2.5} samples were collected using an impactor pre-separator developed for the California Air Resources Board. All filters were desiccated to constant weights before and after sampling.

Polycyclic aromatic hydrocarbons were sampled with an EPA Method 23 sampling train (often referred to as modified Method 5 or MM5), and analyzed for the 16 individual polycyclic aromatic hydrocarbons making-up the 16-PAH list. (The compounds making up the 7-PAH list were also simultaneously quantified as the 7-PAH list is a subset of the 16-PAH list.) Analyses were conducted following EPA Method TO-13A procedures.

Formaldehyde was collected and analyzed by EPA Method SW-846 0011/8315A.

Benzene samples were collected in evacuated stainless steel canisters and analyzed by EPA Method TO-14A (GC/MS Scan). The entire EPA Method TO-14A list was analyzed. Benzene is reported in the text.

Carbon monoxide was measured with a gas filter correlation analyzer following EPA Method 10. The carbon monoxide testing was done separately from the other testing on a second set of tests due to difficulties with the carbon monoxide analyzer encountered during the first set of tests. Background levels of carbon monoxide in the laboratory were routinely measured during testing and found to be less than 1 ppm at all times.

Volatile organic compounds(VOC) were measured with a flame ionization detector analyzer following EPA Method 25A.

Nitrogen oxides (NO_x) concentrations were measured with a chemiluminescent gas analyzer by EPA Method 6C. All gas analyzers were calibrated with EPA Protocol 1 certified gas standards.

Gas flow within the dilution tunnel was measured with a P-type pitot tube and manometer. Chimney, dilution tunnel, and laboratory temperatures were measured with type-K thermocouples and data logged every minute.

Log Composition

The chloride content of each of the firelog combustion residues was determined by EPA Method 300.0. Metals were analyzed in the residue by EPA Method 6010 except for mercury which was analyzed by EPA Method 7471.

The heat content (higher heating value, HHV), as well as, moisture, ash, carbon, hydrogen, oxygen, nitrogen, and sulfur contents of both the firelogs and their combustion residues were determined by proximate/ultimate analyses.

Wax content was determined gravimetrically by weighing the fiber and wax separately after multiple hexane extractions to separate the fiber and the wax. After separation, the wood fiber was sent to the USDA Forest Services' Forest Products Laboratory for tree species identification and the wax was characterized by measuring the percent oil (ASTM Standard D721), carbon count (ASTM Standard D5442), and by needle penetration (ASTM Standard D1321).

The mass of combustion residue produced per unit mass of each firelog burnt was determined gravimetrically by the weight of the logs before the tests and by the weight of the residue left in the fireplace after the tests. Combustion residue is the material remaining after combustion, generally and imprecisely referred to as “ash”. Combustion residue is made up of both char, which is unburned organic material and elemental carbon, and ash, which is composed of inorganic compounds.

Results⁶:

Table 1 contains the pollutant emission factors (mass of pollutant/mass fuel on a dry basis) for each of the five firelog brands individually and the mean emission factors for the firelogs as a group averaged across all five firelog brands for each pollutant. The associated standard deviations are also provided. Table 2 contains the emission factors for each of the individual PAH compounds that make up the 16-PAH list. Values for individual firelog brands and the overall mean PAH compound emission factors for the firelogs as a group averaged across all five firelog brands are shown. The associated standard deviations are provided. The emission factors for some PAH compounds for some firelog brands were below detection limits. When the emission factors were below the detection limit, one-half the detection limit is shown in Table 2 and the one-half detection limit value was used in the calculation of 7-PAH and 16-PAH emission factors shown in Table 1.

Table 3 contains the pollutant emission rates (mass of pollutant/hour of fireplace operation) for each of the five firelog brands individually and the mean emission rates for the firelogs as a group averaged across all five firelog brands for each pollutant. The associated standard deviations are also provided. Table 4 contains the emission rates for each of the individual PAH

compounds that make up the 16-PAH list. Values for individual firelog brands and the overall mean PAH compound emission rates as a group averaged across all five firelog brands are shown. The associated standard deviations are provided. The emission rates for some PAH compounds for some firelog brands were below detection limits. When the emission rates were below the detection limit, one-half the detection limit is shown in Table 4 and the one-half detection limit value was used in the calculation of 7-PAH and 16-PAH emission rates shown in Table 3.

The calculation of emission rates requires fire duration to be defined by a reproducible metric. There is no standardized definition of end time for fireplace emissions tests. The convention used in this study was to divide the total mass of pollutant emitted during the entire sampling period (the total time from the first firelog being lit until the interior chimney temperature had cooled to 5.6°C [10°F] above the laboratory room temperature) by the time that there was a visible flame (the time from the first firelog being lit until the second firelog's flame went out). By using this approach it can be assumed that virtually all pollutants associated with using the firelog are captured/measured and a "standardized," realistic, and easily determined end point is used to characterize the burning duration. The emission rates being calculated in this manner also makes it easier to apply them to the time a home operator burns their fireplace based on visible flame and for comparing the actual burn duration to packaging claims. It should be noted that only a small fraction of the total mass of pollutants are emitted between the time when the last visible flame goes out and when the interior chimney temperature cools to 5.6°C (10°F) above room temperature. Combustion is nearly completed when the last flame goes out.

The mass of residue per mass of fuel (dry basis) remaining after burning the firelog in a normal fashion on an expanded metal overlay on a standard grate in a fireplace is provided in Table 5 for each individual firelog brand. The mean averaged across all firelog brands with its associated standard deviation is also provided.

The results of analysis of the residue are provided in Table 6. Analyses for 26 metals were conducted. These included traditional "toxic" transition and heavy metals and common crustal metals. Chloride analysis was conducted due to the corrosive nature of chloride salts, which can damage fireplaces and their chimneys, and due to the toxic and recalcitrant nature of many chlorinated organic compounds. Standard fuel analysis was also conducted on the residue. The fuel analysis included the heat, moisture, carbon, hydrogen, nitrogen, sulfur, oxygen, and ash contents. Data are provided for each individual firelog brand. The means averaged across all five firelog brands along with their associated standard deviations are provided for each parameter.

Unburned firelogs were characterized by (1) conducting standard fuel analysis (heat, moisture, carbon, hydrogen, nitrogen, sulfur, oxygen, and ash contents), (2) determining the fraction of wax and fiber by hexane extraction, (3) conducting fiber analysis, and (4) conducting standardized wax analyses (needle penetration, oil content, and carbon number distribution). The results of fuel analysis, wax/fiber proportioning and fiber identification are presented in Table 7. The results of the wax analysis are provided in Table 8. It should be noted that while "wax" analyses were used, other materials could be added to wax/fiber logs. These have included molasses, various plant and petroleum oils, and stearic acid. Data for each individual firelog brand are provided in Tables 7 and 8. Where appropriate the means averaged across all five firelog brands with their associated standard deviations are also provided in the tables.

The characteristic burning properties of each firelog brand were documented and the data are shown in Tables 9 and 10. The duration of the fire as determined by when the last flame goes out, by when the interior chimney temperature cools to 38°C (100°F) and by when it cools to 5.6°C (10°F) above room temperature are shown for each firelog brand in Table 9. Two values are shown in the first “flame-out criteria” row in Table 9. One number is for the first log burned during the first set of tests and the second number is for an identical log used in the subsequent carbon monoxide testing that was done separately. The difference between the two numbers illustrates the variability in burn duration among firelogs of the same brand. The mean and maximum interior chimney temperatures during the burning measured 30 cm (1 ft) above the fireplace are shown in Table 10.

Conclusions: All five of the firelogs lit easily and had visible flames for approximately the burning time indicated on the packaging. Beside the understandable health and environmental interest in air emissions, the chemical makeup of combustion residue was measured due to concern over the incidental ingestion of combustion residue (bottom ash) and the common practice of land application of residential wood combustion ash for use as a soil amendment. The overall emission reduction from these logs is consistent with previous studies as shown in Tables 11 and 12. Therefore, the amount of emissions created during the burning period was confirmed in this study.

It was very interesting to see the variation in the composition and amount of emissions created from these logs. The Emission Rates in Table 3 indicated that the Duraflame Easy Time and Xtra Time products produced about twice as much carbon monoxide as the Conros Northland and Pine Mountain products. It should be noted that the Conros Northland product was about half the size of the Duraflame Easy Time and Xtra Time products (1.4 kg vs. 2.3 kg), however it produced the same level of CO as the other Conros product, Pine Mountain which was the same size as the Duraflame products. A similar comparison can be made for Benzene also noted in Table 3. The Residue Analysis noted in Table 6, provide some interesting information about the content of these logs after burning has been completed. The amount of aluminum varies quite significantly from log to log, the same goes for other metals such as barium, copper, magnesium and manganese. Other chemicals such as calcium, potassium and sodium show similar variations.

There are two main components composing these logs, wood fiber and wax. The wood fiber generally consists of cellulose and wood resins act as the glue to hold the cellulose together. Historically, the wax used was a derivative of the petroleum industry. It was a paraffin wax. However, as was explained in the Results section of this report, some manufacturers could be using other products instead of paraffin wax to provide the same purpose.

This paper does not discuss the health issues regarding the amount of metals or chemicals in the residue as the limits vary from province to province and state to state. Any comments would only confuse the reader. The information provided in this paper can be checked individually and compared to local regulatory requirements to address individual concerns regarding health. The application which seems to be popular with this kind of residue is soil enhancement for gardens. Consumption of vegetables from such gardens could be a pathway to measure the impacts of ingestion of these compounds.

We have learned about the emission characteristics from these products and have verified that the levels are lower than for cordwood. The information regarding the content of the firelog before and after burning was quite interesting. The compounds found in the residue may lead to further study to better define their significance.

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**Table 1
Emission Factors**

Pollutant	Units	Java-Log	Northland	Pine Mountain Superlog	Easy Time Firelog	Xtra Time Firelog	Mean ± Standard Deviation
Nitrogen Oxides (NO _x)	g/kg fuel, db	4.8	1.2	9.4	3.1	0.71	3.8±3.5
Volatile Organic Compounds (VOC)	g/kg fuel, db	14.6	22.9	22.4	19.6	19.4	19.8±3.3
Respirable Particles (PM _{2.5})	g/kg fuel, db	11.5	17.5	13.7	13.1	17.5	14.7±2.7
Total Particles (PM)	g/kg fuel, db	11.3	15.6	13.5	14.3	16.3	14.2±2.0
7-PAH*	mg/kg fuel, db	3.2	5.1	3.0	2.6	4.5	3.6±1.2
16-PAH*	mg/kg fuel, db	62.1	62.3	71.4	81.6	93.4	74.2±13.4
Carbon Monoxide (CO)	g/kg fuel, db	57.1	47.3	40.0	88.1	80.2	62.5±20.8
Benzene	g/kg fuel, db	0.42	0.41	0.43	0.64	0.77	0.53±0.16
Formaldehyde	g/kg fuel, db	0.67	1.3	1.1	0.93	0.58	0.92±0.30

*½ of the detection limit value was used for the calculation of 7-PAH and 16-PAH values for compounds that were below detection limits.

Table 2
Polycyclic Aromatic Hydrocarbon (PAH) Emission Factors

PAH Compound	Units	Java-Log	Northland	Pine Mountain Superlog	Easy Time	Xtra Time Firelog	Mean ± Standard Deviation
Naphthalene	mg/kg fuel, db	40.2	38.6	45.9	58.7	60.5	48.8±10.3
Acenaphthene	mg/kg fuel, db	0.5*	0.7*	1.0	0.8	1.2	0.8±0.3
Acenaphthalene	mg/kg fuel, db	3.6	2.2	4.5	2.8	5.6	3.7±1.4
Fluorine	mg/kg fuel, db	2.4	2.2	2.4	2.8	3.9	2.7±0.7
Phenanthrene	mg/kg fuel, db	6.9	8.2	8.5	8.8	10.7	8.6±1.4
Anthracene	mg/kg fuel, db	1.0	0.7*	1.4	1.3	1.4	1.2±0.3
Fluoranthene	mg/kg fuel, db	1.8	2.0	2.3	1.9	2.7	2.1±0.4
Pyrene	mg/kg fuel, db	2.0	1.9	2.3	1.8	2.6	2.1±0.3
Benzo(ghi)perylene	mg/kg fuel, db	0.5*	0.7*	0.1*	0.1*	0.3	0.3±0.3
Benzo(a)anthracene	mg/kg fuel, db	0.5*	0.7*	0.6	0.4	0.8	0.6±0.2
Chrysene	mg/kg fuel, db	0.5*	0.7*	1.2	0.8	1.5	0.9±0.4
Benzo(b)fluoranthene	mg/kg fuel, db	0.5*	0.7*	0.4	0.3	0.9	0.6±0.2
Benzo(k)fluoranthene	mg/kg fuel, db	0.5*	0.7*	0.1*	0.1*	0.1*	0.3±0.3
Benzo(a)pyrene	mg/kg fuel, db	0.5*	0.7*	0.4	0.6	0.8	0.6±0.2
Dibenzo(a,h)anthracene	mg/kg fuel, db	0.5*	0.7*	0.1*	0.1*	0.1*	0.3±0.3
Indeno(1,2,3-c,d)pyrene	mg/kg fuel, db	0.5*	0.7*	0.1*	0.1*	0.3	0.3±0.3

db, dry basis

*1/2 the detection limit

**Table 3
Emission Rates**

Pollutant	Units	Java-Log	Northland	Pine Mountain Superlog	Easy Time	Xtra Time Firelog	Mean± Standard Deviation
Nitrogen Oxides (NO _x)	g/hr	3.3	0.52	6.1	2.0	0.49	2.5±2.3
Volatile Organic Compounds (VOC)	g/hr	9.9	10.3	14.5	13.0	13.5	12.2±2.0
Respirable Particles (PM _{2.5})	g/hr	7.9	7.0	8.9	8.7	12.2	8.9±2.0
Total Particles (PM)	g/hr	7.7	7.9	8.8	9.5	11.4	9.1±1.5
7-PAH*	mg/hr	2.2	2.3	1.9	1.7	3.1	2.2±0.5
16-PAH*	mg/hr	42.2	28.0	46.2	54.1	65.1	47.1±13.8
Carbon Monoxide (CO)	g/hr	35.7	25.3	27.8	61.0	59.7	41.9±17.2
Benzene	g/hr	0.29	0.18	0.28	0.42	0.53	0.34±0.14
Formaldehyde	g/hr	0.45	0.60	0.70	0.62	0.40	0.55±0.12

Note: The g/hr values were calculated by measuring the total grams of pollutant emitted during the entire test and by dividing it by the time that the logs had visible flames.

*1/2 of the detection limit value was used for the calculation of 7-PAH and 16-PAH values for compounds that were below detection limits.

Table 4
Polycyclic Aromatic Hydrocarbon (PAH) Emission Rates

PAH Compound	Units	Java-Log	Northland	Pine Mountain Superlog	Easy Time	Xtra Time Firelog	Mean ± Standard Deviation
Naphthalene	mg/hr	27.3	17.3	29.6	38.9	42.1	31.0±9.9
Acenaphthene	mg/hr	0.3*	0.3*	0.6	0.5	0.8	0.5±0.2
Acenaphthalene	mg/hr	2.4	1.0	2.9	1.9	3.9	2.4±1.1
Fluorine	mg/hr	1.7	1.0	1.6	1.9	2.7	2.0±0.8
Phenanthrene	mg/hr	4.7	3.7	5.5	5.8	7.5	5.4±1.4
Anthracene	mg/hr	0.7	0.3*	0.9	0.8	1.0	0.7±0.3
Fluoranthene	mg/hr	1.2	0.9	1.5	1.3	1.9	1.4±0.4
Pyrene	mg/hr	1.3	0.8	1.5	1.2	1.8	1.3±0.4
Benzo(ghi)perylene	mg/hr	0.3*	0.3*	0.1*	0.1*	0.2	0.2±0.1
Benzo(a)anthracene	mg/hr	0.3*	0.3*	0.4	0.3	0.6	0.4±0.1
Chrysene	mg/hr	0.3*	0.3*	0.8	0.5	1.1	0.6±0.3
Benzo(b)fluoranthene	mg/hr	0.3*	0.3*	0.3	0.2	0.6	0.3±0.2
Benzo(k)fluoranthene	mg/hr	0.3*	0.3*	0.1*	0.1*	0.1*	0.2±0.1
Benzo(a)pyrene	mg/hr	0.3*	0.3*	0.3	0.4	0.6	0.4±0.1
Dibenzo(a,h)anthracene	mg/hr	0.3*	0.3*	0.1*	0.1*	0.1*	0.2±0.1
Indeno(1,2,3-c,d)pyrene	mg/hr	0.3*	0.3*	0.1*	0.1*	0.2	0.2±0.1

*1/2 the detection limit

Table 5
Residue Produced in a Fireplace

	Units	Java-Log	Northland	Pine Mountain Superlog	Easy Time Firelog	Xtra Time Firelog	Mean± Standard Deviation
Residue	g/kg fuel, dry	10	16	11	11	16	12.8±2.9

*Residue is the material remaining after combustion, generally referred to as “ash.” Residue is made up of both char, which is unburned organic material and elemental carbon, and ash, which is composed of inorganic compounds.

Table 6
Residue Analysis

Analysis	Units	Java-Log	Northland	Pine Mountain Superlog	Easy Time Firelog	Xtra Time Firelog	Mean± Standard Deviation**
Aluminum	mg/kg residue, dry	6210	3220	6170	3860	2550	4402±1697
Antimony	mg/kg residue, dry	<10	13	<10	<10	<10	6.6±3.6
Barium	mg/kg residue, dry	338	412	521	1530	469	654±494
Beryllium	mg/kg residue, dry	<1.0	<1.0	<1.0	<1.0	<1.0	0.5
Boron	mg/kg residue, dry	48	90	100	122	97	91.4±27.0
Cadmium	mg/kg residue, dry	1.0	3.2	3.8	3.7	2.7	2.9±1.1
Calcium	mg/kg residue, dry	120,000	46,500	70,600	35,300	26,300	59,740± 37,550
Chromium	mg/kg residue, dry	31	147	21	60	14	54.6±54.5
Cobalt	mg/kg residue, dry	21.3	3.6	2.9	4.6	6.1	7.7±7.7
Copper	mg/kg residue, dry	2190	524	70	274	201	652±876
Iron	mg/kg residue, dry	17,300	2240	3090	3700	2280	5722±6500
Lead	mg/kg residue, dry	<20	23	23	25	28	21.8±6.9
Magnesium	mg/kg residue, dry	12,900	7700	7090	5830	3750	7454±3399
Manganese	mg/kg residue, dry	2470	1170	2790	1410	727	1713±879
Mercury	mg/kg residue, dry	<0.02	<0.02	<0.02	<0.02	<0.02	<0.01
Molybdenum	mg/kg residue, dry	7.6	4.3	2.3	2.3	5.3	4.4±2.2
Nickel	mg/kg residue, dry	124	34	29	20	2730	587±1199
Phosphorus	mg/kg residue, dry	8630	1820	2160	3190	2520	3664±2822
Potassium	mg/kg residue, dry	49,000	60,900	43,600	23,600	33,300	42080± 14344

Table 6 (continued)
Residue Analysis

Analysis	Units	Java-Log	Northland	Pine Mountain Superlog	Easy Time Firelog	Xtra Time Firelog	Mean± Standard Deviation**
Silver	mg/kg residue, dry	<2.0	<2.0	<2.0	<1.9	<2.0	0.99±0.02
Sodium	mg/kg residue, dry	6710	5350	16,000	9220	5330	8552±4470
Strontium	mg/kg residue, dry	188	196	212	204	154	191±22
Tin	mg/kg residue, dry	<10	<10	20	15	<10	8±4
Titanium	mg/kg residue, dry	280	172	413	255	65.3	237±129
Vanadium	mg/kg residue, dry	12	8.3	5.7	5.6	74	21±30
Zinc	mg/kg residue, dry	1410	201	400	283	151	489±523
Chloride	mg/kg residue, dry	95	708	153	43	136	227±272
Heat content	Btu/lb, dry basis	4290	6600	7990	6490	8220	6718±1568
	Mj/kg, dry basis	10.0	15.3	18.5	12.7	19.1	15.1±3.9
Moisture	% dry basis	3.4	10	11	3.2	5.1	6.5±3.7
Carbon	% dry basis	32	44	51	43	53	44.6±8.3
Hydrogen	% dry basis	1.2	2.3	2.9	2.2	2.8	2.3±0.7
Nitrogen	% dry basis	3.1	1.0	4.5	0.77	1.7	2.2±1.6
Sulfur	% dry basis	4.8	1.9	1.8	1.4	2.9	2.6±1.4
Oxygen	% dry basis	29	24	23	21	27	24.8±3.2
Ash*	% dry basis	50	37	25	39	24	35.0±10.8

*Ash here refers to inorganic compounds left after complete, high-temperature combustion in the laboratory.

**When the measured value was less than the detection limit, ½ the detection limit was used in the calculation of the mean and standard deviation

**Table 7
Fuel Characterization**

Analysis	Units	Java-Log	Northland	Pine Mountain Superlog	Easy Time Firelog	Xtra Time Firelog	Mean± Standard Deviation
Moisture	% dry basis	9.5	15	9.8	4.8	4.8	8.8±4.2
Carbon	% dry basis	62	67	72	69	65	67±4
Hydrogen	% dry basis	9.0	9.8	11	10	9.4	9.8±0.8
Nitrogen	% dry basis	1.3	0.29	1.4	0.11	0.33	0.7±0.6
Sulfur	% dry basis	0.23	0.08	0.08	0.08	0.20	0.13±0.07
Oxygen	% dry basis	28	22	18	20	22	22±4
Ash*	% dry basis	0.57	0.58	0.46	0.61	0.47	0.54±0.07
Heat content	Btu/lb, dry basis	12,620	13,540	15,190	14,420	13,770	13,908±964
	Mj/kg, dry basis	29.3	31.4	35.2	33.5	32.0	32.3±2.2
Wax content	%	44	49	55	45	46	47.8±4.4
Fiber content	%	56	51	45	55	54	52.2±4.4
Fiber Identification		coffee grounds	maple, "other" hardwoods, & some bark	unidentified hardwoods & bark (highest % bark of all samples)	maple, birch, "other" hardwoods, & some bark	hardwoods, & some bark, possibly includes willow & poplar	-

*Ash here refers to inorganic compounds left after complete, high-temperature combustion in the laboratory.

**Table 8
Wax Analysis**

Analysis	Units	Java-Log	Northland	Pine Mountain Superlog	Easy Time Firelog	Xtra Time Firelog	Mean± Standard Deviation
Needle Penetration	mm	246	15	289	160	145	171±106
Oil Content	%	34	9.9	16	17	32	22±11
Carbon Number Distribution	% <C13	6.2	5.9	44	10	36	20±18
	% C13-C30	26	68	37	57	53	48±17
	% C31-C50	21	17	14	32	9.8	19±8
	% C51-C70	47	9.8	4.6	0.8	1.4	13±19

**Table 9
Firelog Burning and Sampling Durations in Minutes***

Criteria	Java-Log	Northland	Pine Mountain Superlog	Easy Time Firelog	Xtra Time Firelog
Flame Out, 1 st Log**	165,220	142,161	225,232	188,205	231,221
Flame Out, 2 nd Log	378	335	464	398	458
Chimney Temp. < 100°F (38°C)	472	422	511	508	484
Chimney Temp. < 10°F (5.6°C) above Indoor Temp.	510	438	639	533	627

*Means and standard deviations were not calculated because the firelogs had different masses and their burn durations were inherently not comparable.

**The first number is the flame-out time for the first firelog used in the first set of tests. The second number is for an identical firelog use for the subsequent carbon monoxide testing.

Table 10
Mean and Maximum Temperatures

Temperature	Java-Log °F(°C)	Northland °F(°C)	Pine Mountain Superlog °F(°C)	Easy Time Firelog °F(°C)	Xtra Time Firelog °F(°C)
Mean Chimney*	160(71)	145(63)	160(71)	159(71)	133(56)
Maximum Chimney*	330(166)	225(107)	372(189)	342(172)	245(118)
Mean Room	82(28)	82(28)	77(25)	85(29)	69(21)
Mean Chimney Temp. above Mean Room Temp.	78(26)	63(17)	83(28)	74(23)	64(18)

*Measured 30 cm (1 ft) above fireplace.

Table 11
Comparison of Wax/Fiber Firelog Total Particulate and Carbon Monoxide Emission Rates Measured in This Study with Wax/Fiber Firelog Emission Rates Reported in Previous Studies and with Emission Rates for Cordwood

Pollutant, Units	Wax/Fiber Firelogs		Cordwood
	Mean ± Std. Dev. this study ¹	Mean ± Std. Dev. previous studies ²	Mean ± Std. Dev. previous studies ³
PM, g/hr	9±2	11±5	36±20
CO, g/hr	42±17	25±12	214±65

¹ Five firelog brands this study

² Fifteen firelog brands, 17 test runs (some runs consisted of multiple brands). References 1-5.

³ Cordwood from 9 tree species, 17 runs. References 1-5.

Table 12
Comparison of Wax/Fiber Firelog Emission Rates of Pollutants Measured in This Study with Emission Rates for Cordwood

Pollutant, Units	Mean ± Std. Dev. for Wax/Fiber Firelogs, This Study	Mean ± Std. Dev. for cordwood from a previous study ¹
PM, g/hr	9±2	60±19
PM _{2.5} , g/hr	9±2	57±22
CO, g/hr	42±17	241±30
Formaldehyde, g/hr	0.6±0.1	5±1
Benzene, g/hr	0.3±0.1	1.4±0.4
16-PAH, mg/hr	47±14	730±300

¹ Cordwood from three tree species, four runs. Reference 1