

USE OF CONE CALORIMETER TO ESTIMATE ORGANIC POLLUTANT EMISSIONS FROM OUTDOOR WOOD BURNING BOILERS

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Introduction

As the price of home heating oil, natural gas and liquefied petroleum gas increases, many households are looking for heating alternatives. The Outdoor Wood Burning Boilers (OWB) are one such alternative. An OWB is a wood-fired furnace that is usually housed within a small insulated shed located some distance from a house. The OWBs are a unique emission source with operational and design factors not typically found in other residential wood burning appliances. The OWBs are designed to follow the heat load of a building which means that wood is burned intermittently at lower temperatures and under oxygen-starved conditions to prolong the fuel source. Therefore most OWB units have 30 to 40 percent operating efficiencies¹. The inefficient combustion conditions result in high emissions of particles and unoxidized gaseous compounds, leading to the formation of PAHs and dioxins and dioxin like compounds. A recent study concluded that particle emissions from OWBs are 10 to 20 times higher than certified indoor wood stoves. The OWBs also have large firebox capacity and loading door dimensions that encourages combustion of household waste (e.g., paper, plastic, and packaging) and other non-wood materials. The combustion of non-wood materials in OWBs a device with low stack, no emissions control system, and that operates under low temperature conditions creates the potential for generating hazardous air pollutants in close proximity to homes, schools and businesses. There is no PAH and dioxin (and dioxin like compounds) emission data for OWBs. The objective of this study is to eliminate this information gap and provide reliable PAH and dioxin emission data from OWBs.

Method and Materials

There are wide varieties of woods that are burned in OWBs. It is not known what is emitted when these different types (or combinations) of woods are burned. Due to time and money restrictions it is not possible to conduct full scale studies on all types and combinations of woods and non-wood materials. To overcome this obstacle laboratory study is being conducted to identify the pollutants and their amounts that are emitted during burning of different types of woods and non-wood materials. A cone calorimeter was used to study the pollutant formation/emissions from combustion of various woods and domestic waste under a variety of OWB combustion conditions. The cone calorimeter measures many different parameters of wood combustion, including total heat release for the sample, peak heat release (maximum heat output during the fire), time to ignition, average heat of combustion, and some aggregate indices which relate to flame spread. The instrument also measures mass loss rate, carbon monoxide/carbon dioxide production rates, and smoke density / release rates. By studying the various parameters measured by the cone calorimeter, one can correlate the cone calorimeter measurements to other tests, or, bring understanding of how a material behaves when aflame or exposed to various fire scenarios. The cone calorimeter data has been compared other tests including full scale flammability tests,² bench scale tests like UL-94 or limiting oxygen index,³⁻⁷ automotive material flame spread tests,⁸ wire and cable flame spread tests⁹ and other types of fire tests/scenarios.¹⁰⁻¹³ A schematic of the UDRI cone calorimeter apparatus is shown in Figure 1. The sample sits on a load cell and is exposed to a radiant heat source (cone heater). The heat flux the material sees can be varied from 10 to 100 kW/m², which can mimic a wide range of small to medium scale wood burning (low to high temperature wood burning), as well as burning near and at flashover conditions. The experiments simulate intermittent OWB operation under both oxygen-starved and oxygen-rich conditions. As the wood is burned, gases from the fire are carried past a laser to measure smoke density, and to a sampling ring which carries the gases to a combined CO/CO₂/O₂ detector. Once the gases from the sampling ring have been analyzed, one can obtain CO and CO₂ production rates which

can give insight into the heats of combustion for the material, as well as combustion efficiency. In the University of Dayton cone calorimeter gaseous and particulate emissions are sampled upstream of the sampling (CO/CO₂/O₂) ring. The particles and gases are drawn isokinetically from the sampling port. For this study, a modified EPA method 23 sampling train was connected to the sampling port. This sampling train consists of a heated transfer line connected to a glass fibre filter housed in a heated assembly followed by XAD adsorbent trap and the impingers. The particles captured on the filter were then analyzed for chemical composition (soluble organic fraction) and physical structure of the smoke produced during a fire. The XAD trap and impinger condensates were also analyzed for different classes of pollutants (e.g., dioxins/furans, PAHs and substitute PAHs,) using variety of GC-MS techniques (multi-dimensional and high-resolution GC-MS).

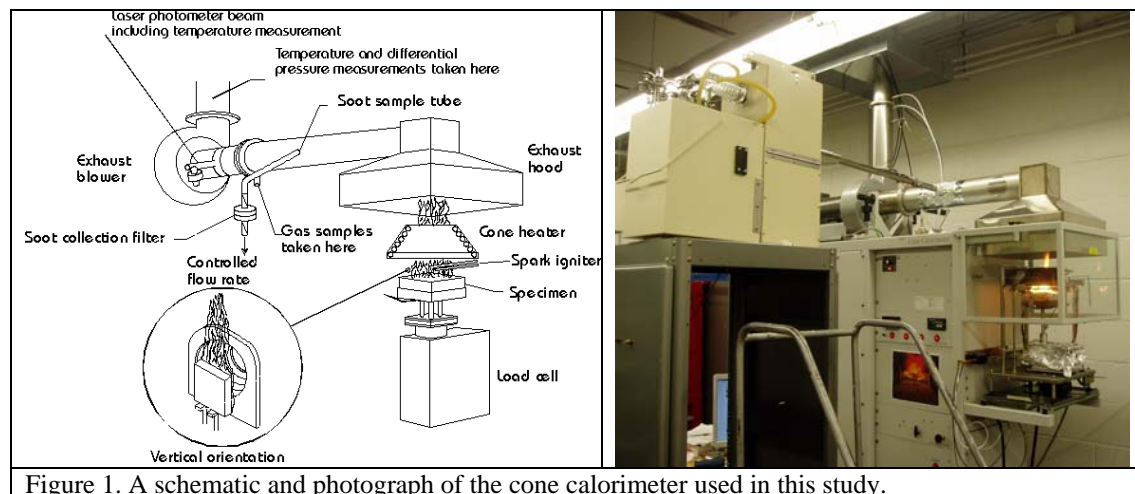


Figure 1. A schematic and photograph of the cone calorimeter used in this study.

For this study, three wood samples were purchased at a local home improvement store and were cut into roughly 100 cm² square samples, each about 19-20mm thick. The three samples were pine, oak, and pressure treated pine, and each was used as received (no drying or humidity conditioning). It was noted that the pressure treated pine samples dried out with time after cutting and warped to some degree as they dried. The experiments were conducted on a FTT Dual Cone Calorimeter following the ASTM E-1354-04 method at one heat flux (50 kW/m²), but some modifications were made to the method. Samples were tested in triplicate without frame and grid, with the back side of each sample wrapped in aluminum foil, but an exhaust flow of 15 L/s rather than 24 L/s was used instead. Further, the sample area used to calculate the heat release rates was measured for each individual sample since no sample was exactly 100 cm² in size as per the ASTM standard.

Results and Discussion

The combined cone calorimeter results are shown in Table 1. The pine results were very reproducible but more scatter was noted with the oak and treated pine samples. Some of these erratic results can be explained by the differences in sample mass, as lighter samples (less total fuel to consume) will obviously generate lower total heat release and smoke release numbers. In general, the oak samples gave the highest heat release and smoke release, followed by the pine sample and then the pressure treated pine, which had the lowest heat release and smoke release. The water content from the pressure treated wood may be responsible for the low heat release and smoke release of these samples though, and it may be worthwhile to analyze these materials again in the future after drying.

The heat release rate curve plots show that all of the samples have a two peak heat release behavior which is typical for a thermally thick charring material. The wood samples always ignited very quickly after exposure to the cone heater, then rose quickly to peak heat release. This was followed by steady burning as the surface of the sample charred and burned away. Right before extinguishment, the heat release would rise again as the last of the combustible fuel was burned off. After the samples flame out, the samples were noted to still glow red (glowing coals) while the cone heater shutters were open, but the glowing stopped upon closing of the shutters

and removal of the sample from the heat. The one exception was the treated pine sample, which continued to glow and stay quite hot for at least 1 hour after removal from the cone heater. The pine and oak samples had cooled within 10 minutes of removal from the instrument, but the treated pine samples maintained temperatures around 300-400 °C (detected by IR thermometer) for a good 20 minutes after the completion of the test. The final chars were black and fragmented as typical of wood samples, but the treated pine sample was lighter, darker in color, and more compact in structure; as if the char shrank during burning.

Table 1. Combined Heat Release Rate data

Sample Description	Sample Thickness (mm)	Time to ignition (s)	Peak HRR (kW/m ²)	Time to Peak HRR (s)	Time to Peak HRR - Tig (s)	Average HRR (kW/m ²)	Starting Mass (g)	Total Mass Loss (g)	Weight % Lost (%)	Total Heat Release (MJ/m ²)	Total smoke Release (m ² /m ²)	Avg. Effective Heat of Comb. (MJ/kg)	MAHRE (kW/m ²)	FIGRA
Pine Board	19.3	17	194	34	17	96	66.7	53.7	80.6	77.3	333	12.76	105	5.71
From Lowe's	19.1	19	205	36	17	104	69.0	56.2	81.5	80.4	280	12.92	109	5.69
	19.5	19	217	36	17	100	72.4	58.5	80.9	81.3	269	12.91	111	6.03
Average Data	19.3	18	205	35	17	100	69.3	56.1	81.0	79.7	294	12.86	108	5.81
Oak Board	19.4	26	227	46	22	135	116.4	91.8	78.9	117.4	494	11.79	137	4.73
From Lowe's	19.2	20	213	42	22	119	89.0	76.7	86.2	92.7	322	12.08	121	5.07
	19.2	18	288	42	24	146	94.0	76.1	81.0	112.9	294	12.56	165	6.85
Average Data	19.3	21	243	44	23	133	99.8	81.5	82.0	107.7	370	12.14	141	5.55
Pressure treated Pine	20.4	20	166	48	28	109	109.8	92.5	84.2	132.0	119	12.10	118	3.45
	20.0	38	174	60	22	96	104.4	86.3	82.7	103.4	61	10.75	94	2.89
	20.0	28	141	48	20	90	107.6	88.6	82.4	94.3	110	10.58	92	2.95
Average Data	20.1	29	160	52	23	98	107.3	89.1	83.1	109.9	97	11.14	101	3.10

The particle and gaseous samples collected on filter and XAD resin were extracted after each experiment. These extracts were then concentrated and analyzed to obtain PAH and chlorobenzenes data. The PAH and chlorobenzenes data is shown in Figures 2 and 3. Figure 2 shows that oak has higher yields for all PAHs. The oak also gave higher yields for chlorobenzenes except for mono and dichlorobenzene which were highest from pine. The PAH and chlorobenzenes data is consistent with the HRR and the total smoke release data. This initial results show that cone calorimeter can be used to understand and estimate pollutant emissions from biomass burning.

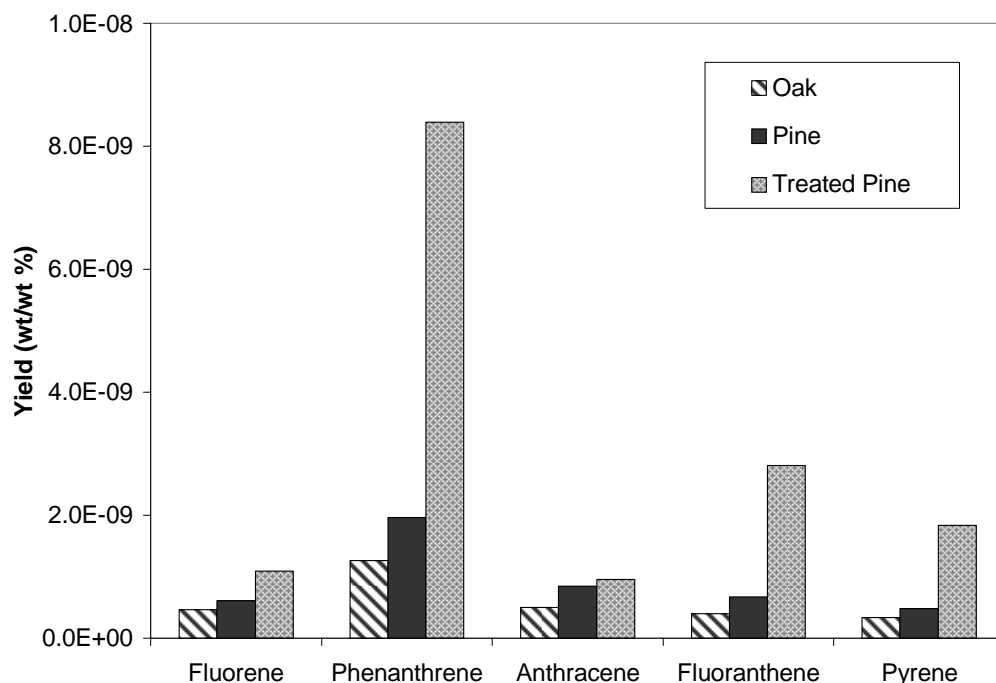


Figure 2. The PAH yields from oak, pine and treated pine combustion.

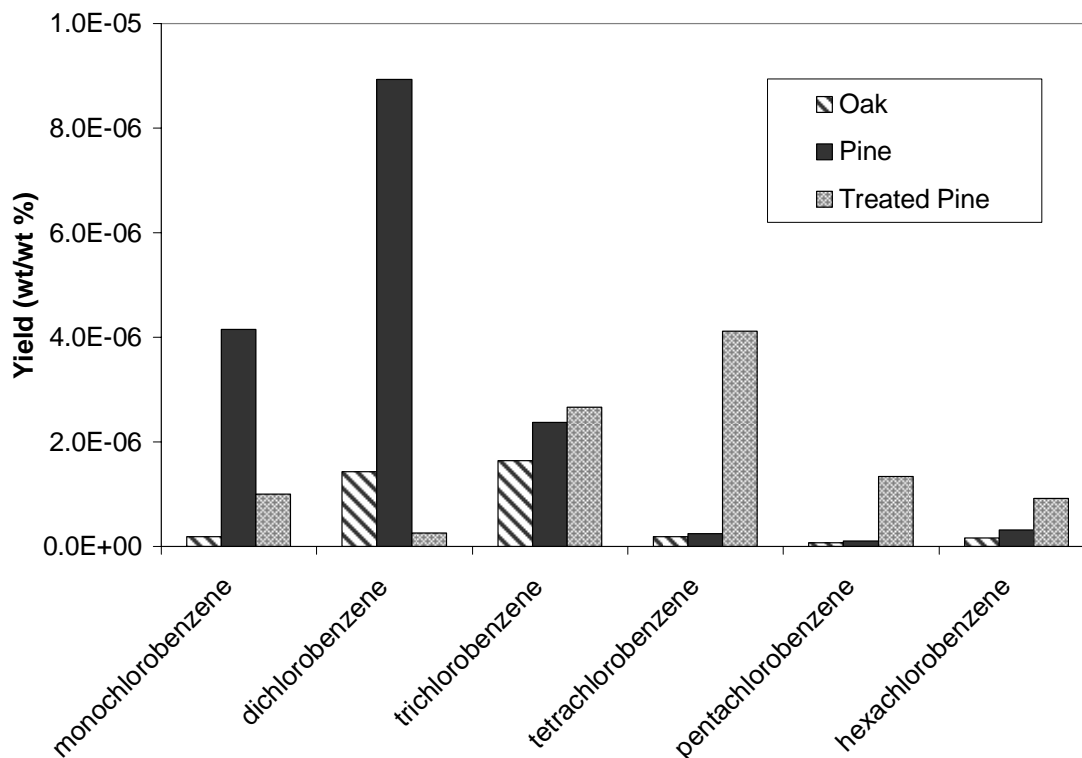


Figure 3. The total chlorobenzene yields from oak, pine and treated pine combustion.

Acknowledgments

This project was funded by The Great Lakes Commission (Project Officer: Jon Dettling)

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