Characterization of carbonaceous aerosols emitted from outdoor wood hydronic heaters

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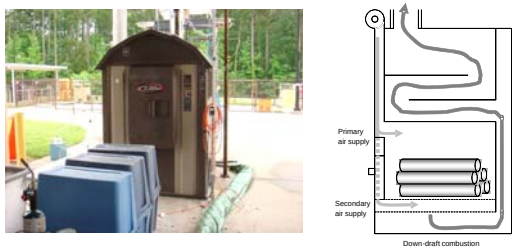
Introduction

Renewed global interest in the domestic combustion of biomass has led to growth in the use of outdoor wood boilers (OWBs) for heating and hot water. Domestic OWBs differ from fireplace and woodstove appliances in that they: (i) operate uncertified and in a cyclic pattern year-round; (ii) can support refuse and pellet burning; and (iii) have low emissions stack heights.

Condition (i) can promote smoldering, which yields more organic aerosol per unit mass of fuel consumed. The odds of offensive OWB emissions penetrating indoors increase with (iii). Hence, there is speculation that OWB may pose a unique and disproportionate human exposure risk.

While substantial proportions of carbonaceous aerosol are expected to be emitted from OWBs, this fraction is seldom characterized. The present study aims to identify and quantify organic indicator compounds emitted from a variety of OWB combustion technologies. Detailed emissions characterization can help produce accurate estimates of near-source exposures. Characterization data are also used to develop new performance standards for OWB and to develop the emissions inventories that support air shed management and air quality policy.



Picture of a efficient OWB [E2300] unit that uses downdraft combustion.

Experimental methods

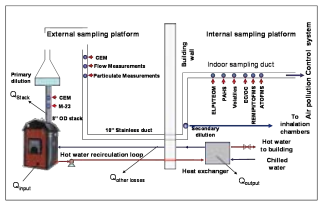
The table below provides specifications for each OWB boiler examined in this study. OWB tests were conducted under ambient conditions at an outdoor EPA test facility located at Research Triangle Park, NC. The OWBs were operated using a 24 h diurnal heat demand profile (for January) for a typical 232 m^2 home in Syracuse, NY, which is located in the northeastern U.S; the heat demand was simulated using a digitally-controlled water-water heat exchanger system.

Unit Model	CL-5036	E2300	ACT	AFB
Manufacturer	Central boiler	Central boiler	Hamont Consulting	Alternative Fuel Boilers
Country of origin	USA	USA	Austria	USA
Technology	Single-stage	Three-stage gasification	Dual-stage gasification	Dual-stage gasification
Firebox volume (m^3)	0.9	0.7	--	0.2
Water capacity (L)	742	1703	162	120
Biomass fuel tested	red oak logs, white pine logs, red oak logs with refuse	Red oak logs	Wood pellets	Red oak logs

Experimental methods (cont.)

Sampling and analysis

OWB emissions were captured using a shrouded, annular hood duct positioned directly above the boiler stack. Emissions were diluted (~10:1) and directed to sampling arrays using a 25.4 cm diameter stainless steel pipe. All dilution tunnel and duct work design and flows complied with ASTM Method E2515 (www.astm.org). The sampling arrays supported a variety of trace gas and particle emissions measurement instrumentation and included a sampling port for animal inhalation studies.



Schematic diagram of OWB test set-up.

There were two sampling ports dedicated to the objective of examining the carbonaceous properties of PM. The first port positioned near the annular duct used a non-heated, isokinetic nozzle (28 L/min). It collected PM at 35-38 °C with a 110 mm glass fiber filter.

A second port downstream collected PM at ~25 °C (21 L/min) using a 47 mm quartz fiber filter. This was a ~15 s grab sample with a filter load optimized for a thermal-optical analysis (TOA).

The 110 mm glass fiber filters were used for gravimetric determinations of PM mass. A duplicate set of three filters—representing the beginning, middle, and end of each test cycle—for each OWB-fuel combination was solvent extracted and then analyzed by gas chromatography-mass spectrometry (GC-MS) to determine the organic aerosol chemical composition.

Results and Discussion

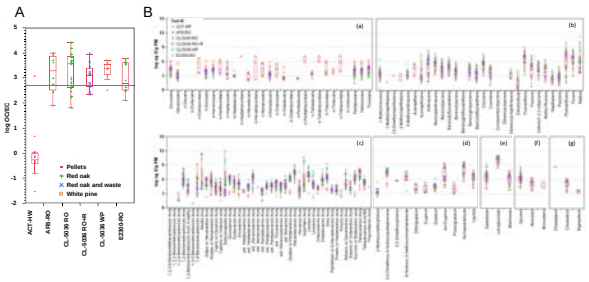


Figure 1. *(A) log-transformed OC-EC ratios and (B) individual SVOC concentrations for the six OWB boiler-fuel combinations.*

Figure 1 illustrates the TOA-determined OC-EC ratio observations (log-transformed, $N \geq 9$) for the five OWB-fuel combinations. . The carbonaceous aerosol component emitted from the boilers burning cord wood is 95% ± 4% w/w OC. The pellet boiler (ACT-HW) produces a significantly higher EC component (53% ± 19% w/w) within the carbonaceous particle fraction.

Results and Discussion (cont.)

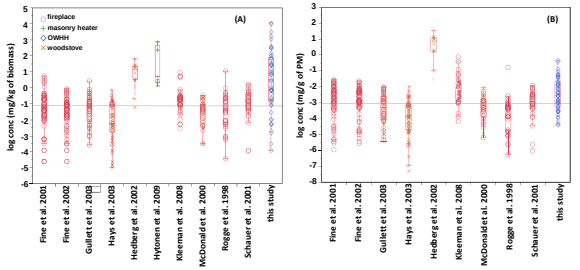


Figure 2. *Aggregate PAH emission factors (log-transformed) for multiple domestic wood combustion studies. An ANOVA model confirmed that wood-burning in the OWB released significantly more PAH per unit mass of wood fuel burned than either fireplace or woodstove appliances with the exception of the Hedberg et al. 2002 woodstove study. (References available on request.)*

Within the domestic wood burning sector, the relative environmental and public health risk posed by OWB emissions is a concern. The polycyclic aromatic hydrocarbons (PAHs) in wood burning emissions are of particular interest owing to their toxicity. It is uncertain currently if OWBs emit more PAHs than common domestic wood-burning appliances such as woodstoves and fireplaces, but investigating such an exposure risk was an objective of this study. To address this matter, the OWB PAH emissions obtained for the present study are compared with literature-based PAH emission factor (EF) values for domestic wood-burning appliances. Figure 2 shows the results of the comparison. The larger EF range for PAH from OWB is likely due to the diversity of combustion technologies in this category.

Conclusions

- With the exception of ACT boiler, mean particle OC-EC ratios show negligible difference ($\alpha = 0.05$) among the OWB boiler technologies.
- The pellet OWB (ACT) released fine aerosols with consistently lower SVOC composition for nearly all compounds.
- OWB design technology (AFB, E2300, and CL5036) had only a slight effect on particle SVOC composition (µg/g PM) when burning red oak wood. Although, the SVOC class emissions per unit mass of fuel burned were noticeably affected by OWB boiler technology and fuel type.
- The addition of refuse to the oak wood fuel had a limited effect on the aerosol SVOC composition; it also generated less heat per unit mass of fuel due to the presence of noncombustible material in the refuse.
- OWBs release significantly more toxic PAH per unit mass of wood fuel burned than more common domestic wood burning appliances, but it uncertain if OWBs emit aerosols with disproportionately high PAH fractions.