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.

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 m² 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.

<table>
<thead>
<tr>
<th>Unit Model</th>
<th>CL-5355</th>
<th>E2300</th>
<th>ACT</th>
<th>APB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>Central boiler</td>
<td>Central boiler</td>
<td>Homart Consulting</td>
<td>Alternative Fuel Boilers</td>
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<td>Country of origin</td>
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<td>USA</td>
<td>Austria</td>
<td>USA</td>
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<tr>
<td>Technology</td>
<td>Single-stage</td>
<td>Three-stage gasification</td>
<td>Dual-stage gasification</td>
<td>Dual-stage gasification</td>
</tr>
<tr>
<td>Firebox volume (m³)</td>
<td>0.9</td>
<td>0.7</td>
<td>–</td>
<td>0.2</td>
</tr>
<tr>
<td>Water capacity (L)</td>
<td>742</td>
<td>1703</td>
<td>162</td>
<td>120</td>
</tr>
<tr>
<td>Biomass fuel tested</td>
<td>Red oak logs, white pine logs, red oak logs with refuse</td>
<td>Red oak logs</td>
<td>Wood pellets</td>
<td>Red oak logs</td>
</tr>
</tbody>
</table>

Figure 1 illustrates the TOA-determined OC-EC ratio observations (log-transformed, N ≥ 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 organic aerosol chemical composition.

Results and Discussion

Experimental methods (cont.)
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.

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.

Conclusions

- With the exception of ACT boiler, mean particle OC-EC ratios show negligible difference (a = 0.05) among the OWB boiler technologies.
- The pellet OWB (ACT) released fine aerosols with consistently lower SVOC emissions per unit mass of fuel burned than either fireplace or woodstove appliances with the exception of the Hedberg et al. 2002 woodstove study. (References available on request.)
- The addition of refuse to the oak wood fuel had a limited effect on the aerosol SVOC class emissions per unit mass of fuel burned. Although, the SVOC class emissions per unit mass of fuel burned were noticeably affected by OWB boiler technology and fuel type.
- 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.