Particle Emissions from Residential Biofuel Boilers and Stoves – Old and Modern Techniques

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Large variations in mass concentration

Total organic compounds TOC (mg/MJ)

Particles (mg/MJ)

- Wood pellets
- Wood logs
- Wood briquettes
- Oil
- Coal
Residential biofuel boilers and stoves in Sweden

12 – 13 TWh

- 260,000 residential boilers fired with wood logs and wood pellets
- 1,100,000 wood stoves and open fires

- 4% Pellet boilers
- 12% Modern wood boilers with storage tank
- 57% Old-type wood boilers with storage tank
- 27% Old-type wood boilers without storage tank
Installed pellet burners (Sweden)

Installed Pellet Burners

- 1997: 5000
- 1998: 10000
- 1999: 15000
- 2000: 20000
- 2001: 25000
- 2002: 30000
## Small-scale combustion in Sweden, fuel comparison

<table>
<thead>
<tr>
<th></th>
<th>Oil</th>
<th>Wood pellets</th>
<th>Oat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Density (kg/m³)</strong></td>
<td>850</td>
<td>650</td>
<td>540</td>
</tr>
<tr>
<td><strong>Heating value (kWh/kg)</strong></td>
<td>11</td>
<td>4.8</td>
<td>4.2</td>
</tr>
<tr>
<td><strong>Volume equivalent to 1 m³ oil</strong></td>
<td>1.0</td>
<td>3.0</td>
<td>4.1</td>
</tr>
<tr>
<td><strong>Price (Swedish Kr)</strong></td>
<td>8500 kr/m³</td>
<td>2200 kr/ton</td>
<td>860 kr/ton</td>
</tr>
<tr>
<td><strong>Price, SEK/kWh</strong></td>
<td><strong>0.91</strong></td>
<td><strong>0.46</strong></td>
<td><strong>0.20</strong></td>
</tr>
</tbody>
</table>
Small – scale biomass combustion: A sustainable renewable energy technology?

Old technology
⇒ large emissions of particles, VOC, CH4 etc (PM from wood combustion larger than from traffic!?)

Modern technology
⇒ potentially low emissions, but depends on fuel quality, operation, maintenance etc
⇒ Oil to biomass may increase local emissions

Very large uncertainties regarding the environmental impact of both old and modern technology
⇒ Detailed emission inventory required
Project Biofuel Health and Environment

Biofuel Health and Environment is a frame project financed by the Swedish Energy Agency.

Synthesis project

- Emissions
- Ambient air
- Health effects

- Year 2000 - 2003
- ~3.3 million Euro
- Totally 25-30 participating Universities, Research Institutes, and Companies

http://www.itm.su.se/bhm
Experimental work
– Emission studies in three projects

1) Old-type and modern wood boilers & pellet boilers. A project within the project Biofuel, Health and Environment

2) Open fireplaces, old-type stoves fired with wood (as well as coal), modern wood stoves and pellet stoves

3) A novel electrostatic precipitator (ESP) for residential combustion was developed and tested in the EU CRAFT project CleanAir.
Old-type wood boiler

- Up-draught combustion
- Water-cooled

Modern wood boiler

- Down-draught combustion
- Ceramic
Modern wood combustion: Boiler + heat storage tank

More optimal combustion conditions => Lower emissions and higher efficiency

The boiler can be run at a constant heat output (instead of being intermittently operated to directly follow the heat load of the house) => Increased convenience
Pellet boilers and burners

Pellet storage

Pellet burner

Boiler

Pellet boiler
Open fires, stoves for wood and pellets

Open fire

Old-type wood stove

Modern wood stove

Pellet stove
Measurement techniques

**VOC, volatile organic compounds**

**PAH, polycyclic aromatic hydrocarbons**

**Particles/Dust**
- Mass concentration

**Particles/Dust**
- Number concentration
- Size distributions, both number and mass

**O₂**, **CO**, **CO₂**, **TOC**, **NOx**
Measurement cases in the 1st project

1. Old-type wood boilers
   • (a) Large and small wood batches fired without heat storage tank, (b) combustion with connection to heat storage tank
   • Dry birch wood (15 % moisture content)

2. Modern wood boilers
   • Connected to a heat storage tank
   • Dry and moist (26/38 %) birch wood, wood briquettes

3. Pellets boilers (and burners)
   • Nominal load, intermittent operation, high draught
   • Wood pellets, bark pellets

4. Oil boiler (and burner)
Measurement cases in the 2nd project

1. Open fire place (1)
2. Old-type wood stoves (2)
3. Modern wood stoves (2)
4. Pellet stoves (2)
Fuels

**Wood/Pellets:** 19 MJ per kg dry fuel

Content, mass-% in dry fuel.

<table>
<thead>
<tr>
<th>C</th>
<th>O</th>
<th>H</th>
<th>N</th>
<th>S</th>
<th>Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-51</td>
<td>43-44</td>
<td>~6</td>
<td>0.05-0.08</td>
<td>&lt;0.01</td>
<td>0.3-0.5</td>
</tr>
</tbody>
</table>

Moisture: 7 – 8 % for pellets, 16 % for dry wood logs and 26 and 38 % in the cases of moist wood logs.

**Coal:** Coalite (Coalite ltd). ~50 % higher heating value than wood/pellets, 15 times more ash. More carbon, nitrogen and sulphur, but lower content of hydrogen and oxygen than in the biofuels.

**Oil:** Slightly twice as high heating value as wood/pellets, about the same ash content. More carbon, hydrogen, nitrogen and sulphur, but lower content of oxygen than in the biofuels.
Prototype tests
• Laboratory tests
• Validation at household site
The CleanAir unit
The novel ESP was shown to reduce 86 ±4 % of the particle mass, in case of old-type wood stove, resulting in a particle emission of 4 mg/MJ.
Large variations in number concentration

1*10^11*Particles (#/MJ)

Total organic compounds TOC (mg/MJ)

- Wood pellets
- Wood logs
- Wood briquettes
- Oil
- Coal
Large differences between boiler types
Mass size distributions 1 (2)

Particles

$\frac{dm}{d\log(Dp)}$ (mg/m$^3$)

Water-cooled multi-fuel boiler, small wood batches
Ceramic-lined wood boiler, natural draught

Pellet boiler
Pellet burner with pilot flame
Pellet burner with electrical ignition
Mass size distributions 2 (2)

![Graphs showing mass size distributions for different systems and phases.](image)

- **Old-type wood boiler**
- **Modern wood boiler, storage tank**
- **Pellet burner pilot flame**
- **Pellet burner el. ignition**
- **Pellet stove**
Number size distributions 2 (2)

- Old-type wood boiler, large wood batches
- Old-type multi-fuel boiler, small wood batches
- Old-type wood boiler, small wood batches
- Old-type wood boiler, storage tank

- Ceramic wood boiler, flue gas fan, wood logs 15% moisture
- Ceramic wood boiler, flue gas fan, wood logs 26% moisture
- Ceramic wood boiler, flue gas fan, wood logs 38% moisture

- Pellet burner with el. ignition, 22 kW/nominal
- Pellet burner with el. ignition, 6 kW, intermittent
- Pellet burner with el. ignition, 3 kW, intermittent
- Pellet stove, nominal output
Conclusions

1. The residential biofuel boilers in Sweden are dominated by old-type wood boilers with high emissions => There are large possibilities to decrease the emissions by changing to modern boilers and install heat storage tanks

2. Particle emissions are dominated by submicron sizes, with respect to mass as well as number

3. The variations in emissions are large => emission data for particles need to be further investigated with respect to real conditions at people’s homes (on-going work today)

4. The novel ESP indicates future possibilities to further reduce particle emissions
Financial support from

- The Swedish Energy Agency
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