Biomass Combustion in Europe

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Biomass Combustion in Europe

1. Introduction
2. Fundamentals
3. One-stage combustion
4. Two-stage combustion for high burnout
   a) Log wood, b) Pellets c) Automatic Boilers
5. Particle emissions
6. NO\textsubscript{x} emissions
7. Other pollutants
8. Conclusions
The fossil Period: A Peak in History
1. Heat
2. Power
3. Transport?
CO₂ \rightarrow CO + C_{org} + C_{el}

KCl, CaCO₃

NOₓ+N₂

C, Ca, K, N

Ca, K, ...

hν
Sustainability Requirements for Bioenergy

1. Sustainable biomass production:
   No deforestation!

2. Social aspects:
   Biomass for food first, no competition

3. Ecological aspects:
   Acceptable air pollution
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Flame Principles

Diffusion Flame

Premixed Flame

c.a. 1000°C

1540°C
1560°C
520°C
300°C
Wood Combustion with Air

\[ \lambda = \text{Excess air ratio} = \frac{\text{Air}}{\text{Air}_{\text{stoch}}} = \frac{O_2}{O_2_{\text{min}}} \]

\[
\text{CH}_{1.4}\text{O}_{0.7} + \lambda (O_2 + 3.76 \text{N}_2) \rightarrow \text{Intermediate Products (CO, H}_2, C_m\text{H}_n,\ldots) \\
\]

\[
\text{CO}_2 + 0.7 \text{H}_2\text{O} + (\lambda-1) O_2 + \lambda 3.76 \text{N}_2 + 18.3 \text{ MJ/kg}
\]
Correlation between CO and Hydrocarbon (HC)

HC und CO in [mg/m³] bei 11 Vol% O₂

Open Chimney
Log Wood Boiler
Automatic Wood Chip Boiler (under stoker)

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[Nussbaumer 1989]
Requirements for Complete Burnout: T | T | T

Temperature – Time – Turbulence (Mixing)

> 850°C (dry wood $\lambda < 2$

Re > 2300

2-stage Comb. with primary & secondary Air Ventilator
Mixing zone
T ($\lambda$) Influence of excess air on Temperature

- Excess air ratio $\lambda$
- Dry wood

Graph showing the relationship between temperature $T$ and excess air ratio $\lambda$. The graph includes lines for different humidity levels ($u=0\%$, $u=20\%$, $u=40\%$, $u=80\%$) and a shaded area for dry wood.
Group of Pollutants from Wood Combustion

\[ \text{CH}_{1.4}\text{O}_{0.7} + \text{O}_2 \rightarrow \text{CO}_2 + 0.7 \text{H}_2\text{O} \]

1. CO, C\text{X}H\text{Y}, C_{\text{org}}, \text{soot} ...

2. NO\text{X}, \text{PM}

3. KCl, K\text{2}SO\text{4}, CaCO\text{3} ...

K, Ca, Na, Cl, S.. →
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1-stage combustion

Air + Air → CO₂, H₂O, O₂, N₂, CO, CₓHᵧ

at \( \lambda > 1 \)
Influence of Excess Air Lambda on CO

1-stage combustion

CO (\lambda)

Eta (\lambda)
Limitations of 1-stage Combustion

Problem 6: Flame Quenching

Problem 5: Heat Extraction in Combustion Zone

Problem 4: Gas Leakage

Problem 3: Air Leakage

Problem 2: Mixing Air + Gas

Problem 1: Air Distribution
1-stage Combustion Wood Stove

Eta < 60%
Organic PM / Tar

[Image of organic PM / Tar]

Kägi & Schmatloch 2002

Soot

[Image of soot]

Heuberger in Klippel & Nussbaumer 2007

Hochschule Luzern
Engineering & Architecture
1-stage Combustion with Combustion Chamber

Air
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2-stage Combustion with forced Downdraft

Wood: \( \text{CHO} \)

\[ + \text{Air } \lambda < 1 \]
\[ \frac{\text{O}_2 + \text{N}_2}{\text{CO}, \text{H}_2, \text{C}_x\text{H}_y} \]

\[ + \text{Air } \lambda > 1 \]
\[ \frac{\text{O}_2 + \text{N}_2}{\text{CO}_2, \text{N}_2} \]

\[ \text{CO}_2, \text{H}_2\text{O}, \text{N}_2 \]

\( \text{Eta} > 90\% - \text{Heat Storage} \)
2-stage Combustion with forced Downdraft

Premixed flame
2-stage Combustion with Downdraft and Grate
Influence of Excess Air Lambda on CO

Downdraft boilers are sensitive for channelling and bridging -> not suited for fine wood (dust) or very large logs!
Prototype 2-stage Stove

Tiba (Switzerland)
2-stage Combustion Stove in Operation
Pellet Boiler with Automatic Ignition

Hargassner (Austria)
Pellet Boiler with Grate for periodic Ash Removal

Liebi LNC AG (Switzerland)
Under Stoker Boiler

\[ w \approx 10\% - 50\%, \quad a < 5\% \]

200 kW ... 2 MW

Grate Boiler

\[ w \approx 10\% - 55\%, \quad a < 50\% \]

400 kW ... >10 MW
Grate Boiler

\[ w \approx 10\% - 55\%, \ a < 50\% \]

400 kW ... >10 MW

Schmid (Switzerland)
District Heating 6.4 MW

Schmid AG, Wilderswil, Interlaken (Victoria-Jungfrau)
Burnout quality

[Bruch & Nussbaumer, 1998]
Velocity Distribution, 900 kW Grate Furnace

Centre plane
Prim. air ratio $\lambda = 0.7$
Sec. air ratio $\lambda = 1.1$
EBU Comb.-model

[Bruch & Nussbaumer, 1998]
Fluid Dynamics: Model Laser Camera

[Brzovic, Nussbaumer & Baillifard, 2007]
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Verleicht der Toxizität verschiedener Partikel

**Wood stove with bad operation**

Toxizität = 10

**Wood soot and tar (condens.)**

**Diesel car without particle filter**

Toxizität = 1

**Diesel soot**

**Automatic wood furnace**

Toxizität < 0,2

**Ash particles = salts**
Results of Cytotoxicity Tests

Cell Survival

Particle concentration in cell medium [μg/ml]

Survival [%]

Diesel soot

Inorganic particles (AWC)

Similar for empty filter!
Results of Cytotoxicity Tests

Cell Survival

Survival [%]

Particle concentration in cell medium [µg/ml]

Diesel soot

particles from bad combustion conditions in a small wood stove
<table>
<thead>
<tr>
<th>Origin</th>
<th>Form</th>
<th>Filter at 180°C (VDI)</th>
<th>Impinger after filter (EPA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salts</td>
<td>Ash</td>
<td>solid</td>
<td>+</td>
</tr>
<tr>
<td>Soot</td>
<td>Incom-plete combustion</td>
<td>liquid</td>
<td>−</td>
</tr>
<tr>
<td>Tar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emmission Type</td>
<td>Typically Operated Wood Stove</td>
<td>Ideally Operated Wood Stove</td>
<td>Badly Operated Wood Stove</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------------------</td>
<td>-----------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>Salts</td>
<td>100</td>
<td>&lt; 20</td>
<td>100</td>
</tr>
<tr>
<td>Soot</td>
<td>&lt; 5</td>
<td>&lt; 20</td>
<td>100</td>
</tr>
<tr>
<td>Tar</td>
<td>&lt; 5</td>
<td>&lt; 5</td>
<td>400</td>
</tr>
<tr>
<td>Total PM</td>
<td>&lt; 100</td>
<td>&lt; 50</td>
<td>500</td>
</tr>
</tbody>
</table>

Typically operated wood stove

Ideally operated wood stove

Badly operated wood stove

Automatic wood combustion

Typical Emissions (mg/m³ @ 13 Vol.-% O₂)

\[ \text{mg/MJ} = 0.68 \times \text{mg/m}^3 @ 13 \text{ Vol.-% O}_2 \]
Particle precipitation

Pre dedusting > 5 µm

- Cyclone

Fine particle removal < 10 ... < 0.01 µm

- Electrostatic Precipitator (ESP)
- Fabric filter (FF)

Raw gas → Clean gas

Condensation!
C-content < 2%

Verenum
Particle precipitation

Pre dedusting > 5 µm

Cyclone

Fine particle removal < 10 ... < 0,01 µm

Electrostatic Precipitator (ESP)

Fabric filter (FF)

Aerob-Beth

Scheuch

Raw gas → Clean gas

Condensation!

C-content < 2%

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Conversion of Fuel-Nitrogen

N in Fuel -NH₂ → Temp → HCN → NH₃ → O₂ → NO → N₂
\[ \lambda = 0.7 \]

\[ \text{NO} + \text{NH}_2 \rightarrow \text{N}_2 + \text{H}_2\text{O} \]

[Keller & Nussbaumer, 1994]

[Salzmann & Nussbaumer, 2004]
Air staging and Fuel staging

[Salzmann & Nussbaumer, 2001]

[Fastenaekels & Nussbaumer, 2002]
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PCDD/F as a function of carbon burnout

[Oehme et al. 1987]
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Conclusions (1/2)

1. Biomass combustion exhibits a relevant potential
2. Efficiencies of > 80% are achievable in small and medium scale
3. Wood combustion can cause PM, PAH, CO, VOC
4. Wood combustion is a major source of organic PM today
5. PM consists of salts (s) soot (s) & organic condensables
6. Salts from automatic plants are less toxic than soot and can be reduced by secondary measures
7. Soot and organic condensables are highly toxic and need to be reduced from manual combustion
8. Two-stage combustion at optimum excess air ratio thanks to ideal operation and/or advanced combustion control enables high combustion quality
Conclusions (2/2)

1. Wood stoves and old or simple wood boilers often
   – exhibit no real two-stage combustion
   – exhibit too small combustion chamber if filled
   – miss heat storage
   – are not capable to be operated at part load after filling
   – can be operated with lack of oxygen

2. An environmentally friendly use of wood in residential applications is a huge challenge and needs improvement in technology, application, and regulation

3. All other fuels than natural wood (agricultural biomass, waste) can lead to significantly higher air pollution, i.e., PM, NO\textsubscript{X}, HCl, PCDD/F, heavy metals) and need to be restricted to large plants with flue gas cleaning
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www.verenum.ch