Advanced combustion control for a wood log stove, Expert workshop - Highly Efficient and Clean Wood Log Stoves

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Advanced combustion control for a wood log stove

Expert workshop - Highly Efficient and Clean Wood Log Stoves
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Intelligent Heat System
High-energy efficient wood stoves with low missions

- Collaboration between HWAM A/S and DTU Chemical Engineering
- Periode 2011 – 2015
- EUDP - project
  (Energy Technology Development and Demonstration Program)

Development of a new automatically controlled wood stove with:
- High energy efficiency
- Reduced emissions (CO, particles etc.)
- High comfort for the wood stove users
Main results

• A new advanced control system has been developed based on experiments conducted at experimental facilities at HWAM og DTU Chemical Engineering

• HWAM has launched an automatically controlled modern wood stove on the market

• Field and laboratory tests has shown reduced emissions and higher efficiency for stoves with the control system - and high comfort for the wood stove users
Content

• Background for the project – why an automatic control system?

• Concept of the automatically controlled wood stove

• Our results from
  – Field tests
  – Experiments at the wood stove set-up at DTU Chemical Engineering
Regulation and legislation

New wood stoves are approved according to national and European standards.

Standards:

<table>
<thead>
<tr>
<th>Approval of Wood stoves</th>
<th>Eff. (%)</th>
<th>CO (mg/Nm$^3$)</th>
<th>PM (mg/Nm$^3$)</th>
<th>PM (g/kg)</th>
<th>OGC (mg/Nm$^3$)</th>
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<td>Danish Statutory of order</td>
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<td>&lt;5</td>
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<td>Swan label (optional)</td>
<td>≥76</td>
<td>≤1250</td>
<td>&lt;3</td>
<td>&lt;100</td>
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<td>Swan label (from 2017)</td>
<td>≥76</td>
<td>≤1250</td>
<td>&lt;2</td>
<td>&lt;100</td>
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</tbody>
</table>

The emissions can be much higher when the stoves are used by ordinary wood stove users.
Challenges

The emission level can be high due to challenging conditions:

• batch firing in small combustion chambers

• wide range of various wood types and wood log sizes

• combustion air flows and fuel loads are manually controlled

Difficult to achieve an optimal combustion
Improved technologies

Modern stoves with air staging:

Three combustion air inlets:

- Primary air at the bottom (ignition)
- Secondary air at the top of the front window (air-wash, second combustion)
- Tertiary air at the back wall (high temperature gas combustion)

However, well-designed stoves can also cause high emissions and low efficiency
Field tests – measurements at stoves in private homes

Measured 1 week:
- Existing (modern) stove
- Automatically controlled wood stove
- \( O_2, CO_2, CO \), flue gas temp.
- Amount of wood
- Temp. in– and outdoor

It is difficult to control the combustion air flows manually in an optimal way.
Lack of combustion air in the flame phase and too much air in the char combustion phase

One combustion cycle
Manually controlled wood stove – 2

A large potential for improving the combustion process by optimizing the combustion air flows.

High excess air and temperature in both the flame phase and the char combustion phase.

Four combustion cycles.
Automatically controlled wood stove

Modern wood stove

+ Air box (3 motor-controlled valves and a software program)

+ Process control (the process parameters are the O$_2$ concentration and the temperature in the flue gas)

+ Remote control to starts the combustion and set the room temperature
Control of the air supply

The three air inlets are automatically controlled by

• a software program based on the definition of *five combustion phases*

• and the process parameters – measured *temperature and O₂ in the flue gas*
Software – overall concept

Phase 0
(Cold stove)
- Primary
- Secondary
- Tertiary

Regulation: None

Phase 1
(Ignition)
- Primary
- Secondary
- Tertiary

Regulation: Temp. and O₂

Phase 2
(Flame)
- Primary
- Secondary
- Tertiary

Regulation: Temp. and O₂

Phase 3
(Char combustion)
- Primary
- Secondary
- Tertiary

Regulation: Temp. and O₂

Phase 4
(Shut down)
- Primary
- Secondary
- Tertiary

Regulation: None

Phase Change:
Temperature, O₂ and air flow – in combination
Temperature and O₂ concentration constant and optimal during most of the combustion cycle

**Phase 1:**
- Ignition of wood
- A few minutes

**Phase 2:**
- Combustion of pyrolysis gases
- Intensive combustion with flames.
- 25 - 30 minutes

**Phase 3:**
- Combustion of char
- The combustion intensity decreases
- The temperature decreases, the O₂ and CO emission increase
The same user

Manually controlled

Lack of combustion air in the flame phase and too much air in the char combustion phase

Automatically controlled

Stable $O_2$ and temperature, and low CO
The same user

Manually controlled
High excess air and temperature in both the flame phase and the char combustion phase

Automatically controlled
Lower $O_2$ and temperature, and *much* higher efficiency
Experimental setup

Including: woodstove, stack, dilution tunnel, sampling sites, filters for particle collection and panel for gaseous analysis.

PM measurements:
• Filter collection based on the Noweigan Standard NS-3058
• Scanning mobility particle sizer (SMPS)
- Increase in CO/VOC/PM in phase 1
- PM peak in phase 2 but low CO/VOC
- Increase in CO (VOC) but low PM in phase 3
PM composition

- Condensable organic compounds
  Example hexane ($T_{\text{boil}} = 69 \, ^\circ\text{C}$)
  Example benzene ($T_{\text{boil}} = 80 \, ^\circ\text{C}$)
  Initial release of volatiles from fuel
  Temperature/mixing in the combustion zone

- Soot/Black carbon
  High temperature & $O_2$ lean formation
  Potentially caused by insufficient mixing

<table>
<thead>
<tr>
<th>Charge</th>
<th>Time (0-15 min)</th>
<th>Time (15-30 min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.8 ± 0.2 g / kgdry</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.8 ± 0.8 g / kgdry</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1.4 ± 0.4 g / kgdry</td>
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</tr>
<tr>
<td>4</td>
<td>0.5 g / kgdry</td>
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Conclusions

• A first version of an automatically controlled wood stove, HWAM IHS, has been developed and launched on the market.

• Results from a development and demonstration project have shown significantly reduced emissions and high efficiency for the automatically controlled stoves compared to manually controlled stoves.

• The new control system ensures improved stove operation even when used by private wood stove owners.
Thanks for your attention