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>≤1250</td>
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<td>&lt;3</td>
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<td>Swan label (from 2017)</td>
<td>≥76</td>
<td>≤1250</td>
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<td>&lt;2</td>
<td>&lt;100</td>
</tr>
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</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
- O₂, CO₂, 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.

Field tests in six private homes
Manually controlled wood stove – 1

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

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

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

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 $O_2$

Phase 2
(Flame)

- Primary
- Secondary
- Tertiary

Regulation: Temp. and $O_2$

Phase 3
(Char combustion)

- Primary
- Secondary
- Tertiary

Regulation: Temp. and $O_2$

Phase 4
(Shut down)

- Primary
- Secondary
- Tertiary

Regulation: None

Phase Change:
Temperature,
$O_2$ and air flow –
in combination
Temperature and \( O_2 \) 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 deceases  
- The temperature decreases, the \( O_2 \) and CO emission increase
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
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>
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<tr>
<th>Charge</th>
<th>Mass (g/kg dry)</th>
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<tbody>
<tr>
<td>1</td>
<td>1.8 ± 0.2</td>
</tr>
<tr>
<td>2</td>
<td>1.8 ± 0.8</td>
</tr>
<tr>
<td>3</td>
<td>1.4 ± 0.4</td>
</tr>
<tr>
<td>4</td>
<td>0.5</td>
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</table>
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