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

Illerup, Jytte Boll; Hansen, Brian Brun; Lin, Weigang; Nickelsen, Joachim; Dam-Johansen, Kim

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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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Jytte Boll Illerup
Brian Brun Hansen
Weigang Lin
Joachim Nickelsen
Kim Dam-Johansen

DTU Chemical Engineering
Department of Chemical and Biochemical Engineering
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>
<td>&lt;3</td>
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<td>Swan label (from 2017)</td>
<td>≥76</td>
<td>≤1250</td>
<td>&lt;2</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.
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\textsubscript{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 O$_2$ 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
Standard combustion cycle

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

Automatically controlled
Lower O₂ and temperature, and much higher efficiency

The same user
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 ($T_{boil} = 69 \, ^\circ C$)  
  *Example* benzene ($T_{boil} = 80 \, ^\circ C$)  
  *Initial release of volatiles from fuel*  
  *Temperature/mixing in the combustion zone*

- Soot/Black carbon  
  *High temperature & O₂ lean formation*  
  *Potentially caused by insufficient mixing*

$$
\begin{align*}
\text{Charge 1: } & 1.8 \pm 0.2 \, \text{g / kgdry} \\
\text{Charge 2: } & 1.8 \pm 0.8 \, \text{g / kgdry} \\
\text{Charge 3: } & 1.4 \pm 0.4 \, \text{g / kgdry} \\
\text{Charge 4: } & 0.5 \, \text{g / kgdry}
\end{align*}
$$
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