Intelligent Heat System – High-Energy Efficient Wood Stoves with Low Emissions

Seminar on
Real-world emissions from residential wood combustion
Copenhagen 3 December 2015

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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 wood stove on the market

• Field and laboratory tests have shown reduced emissions and higher efficiency for stoves with the control system
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>≤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>
<td>&lt;100</td>
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</tbody>
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The emissions can be much higher when the stoves are used by ordinary wood stove users.
Challenges

This is due to challenging conditions when using a wood stove:

- batch firing in a small combustion chamber
- use of different wood types and wood log sizes
- combustion air flows and the fuel load 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 manually the combustion air flows 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

Four combustion cycles
Two combustion cycles

First cycle:
Lack of combustion air in ignition and flame phase and high excess air in char combustion phase.

Second cycle:
Wood with high moisture content
Long period with insufficient air and wet wood results in low efficiency and very high CO.
Manually controlled wood stove – 4

Chimney fane
High excess air, low efficiency and high CO

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

Three 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 start 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
Overall concept of the software

Phase 0  
(Cold stove)

- Primary
- Secondary
- Tertiary

Regulation: None

Phase Change:

Temperature, 
O₂ and air flow – in combination

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: None

Phase 4  
( Shut down)

- Primary
- Secondary
- Tertiary

Regulation: None
**Standard combustion cycle**

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 decreases
- 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 and optimal $O_2$ 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 but low CO/VOC in phase 2
- 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

Charge 1: 1.8 ± 0.2 g / kgdry
Charge 2: 1.8 ± 0.8 g / kgdry
Charge 3: 1.4 ± 0.4 g / kgdry
Charge 4: 0.5 g / kgdry
Conclusions

• An automatically controlled wood stove, HWAM IHS, has been developed and launched on the market.

• Results 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 - also when used by private wood stove owners.
Thanks for your attention