Challenges in Combustion of Low Grade Biomasses – Recent Research

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Turku, Finland
Low Grade Biomasses:
The Devil is in the *Chemical* Details

*Courtesy by Foster Wheeler and Metso*
Low Grade Biomasses: The Devil is in the *Chemical* Details

- Is all ash alkali active in flue gases?
- $\text{NO}_x$ – the role of char nitrogen?
- Ash deposits on surfaces – do they change?
- How do we know if CFD results are right?

Courtesy by Foster Wheeler and Metso
Fuel types

- Miscanthus (AUT)
- Reed (FIN)
- Wheat straw (DEN)
- Suger cane bagasse (THA)
Fuel analysis

Reed (FIN)

<table>
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<tr>
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Miscanthus (AUT)

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Wheat straw (DEN)

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Bagasse (THA)

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Wire Mesh – Grid Heater

- Electrically heated wire mesh in a reactor purged with $N_2$
- Small and well-defined samples
- Close temperature control

Temperature History of the Wire Mesh

- Heating time
- Holding time
- Cooling time

Rate: 1000 K/s
1 - 4 sec.
Initially fast

Residence time
Potassium Retention in Mesh Pyrolysis - Raw Data

<table>
<thead>
<tr>
<th></th>
<th>TS (mg)</th>
<th>Pyr?</th>
<th>T (°C)</th>
<th>Tid (s)</th>
<th>Char (mg)</th>
<th>K (ppb)</th>
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Retention of Biomass Potassium in Pyrolysis - Wire Mesh Tests (1000 K/s)

Retention of Potassium in Pyrolysis - Summary

Primary release in 850°C

- Straw
- Reed
- Miscant.
- Bagasse

Retention of K (%) vs. Holding time (s)

Primary release in 1000°C

- Straw
- Reed
- Miscant.
- Bagasse

Retention of K (%) vs. Holding time (s)

Fuel analysis
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- Is all ash alkali active in flue gases?
- $\text{NO}_x$ – the role of char nitrogen?
- Ash deposits on surfaces – do they change?
- How do we know if CFD results are right?
What happens with the mass of a 6 mm particle if we introduce it to 1000 °C and 21% O₂?

How much NO is coming out from the particle during char oxidation?
NO Formation during Biomass Char Burn-Out
(900°C, 10 % O₂)

Char-C + O₂ → CO/CO₂

Char-N + 1/2O₂ → NO

NO + Char-C → CO + 1/2N₂

NO + CO → CO₂ + 1/2N₂
Concentrations of NO and O₂ inside and outside particle considered:

\[
D_{O_2} \left( \frac{d^2 C_{O_2}}{dr^2} + \frac{2}{r} \frac{dC_{O_2}}{dr} \right) \quad - k_{O_2} C_{O_2} = 0
\]

\[
D_{NO} \left( \frac{d^2 C_{NO}}{dr^2} + \frac{2}{r} \frac{dC_{NO}}{dr} \right) \quad - k_{NO} C_{NO}^n + \xi k_{O_2} C_{O_2} = 0
\]

\[
D_{O_2} \left( \frac{d^2 C_{O_2}}{dr^2} + \frac{2}{r} \frac{dC_{O_2}}{dr} \right) = 0
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\[
D_{NO} \left( \frac{d^2 C_{NO}}{dr^2} + \frac{2}{r} \frac{dC_{NO}}{dr} \right) = 0
\]
As particle decreases in size, NO diffuses away at a faster rate. Less NO reduced & more NO is released.
Char NO Formation – Model vs. Experiments

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Courtesy by Foster Wheeler and Metso
Temperature Gradient across Superheater Tube

- Tube wall (5 mm) at $T_{\text{steam}} = 500 \, ^\circ\text{C}$
- Ash deposit (2.3 mm) at $T_{\text{gas}} = 1000 \, ^\circ\text{C}$
- Heat flux $= 80 \, \text{kW/m}^2$

Engblom M. et al 2013
Material sample rings

Thermocouples

Length ~60 cm
Setup
Deposit Probe with Temperature Gradient

Diagram showing the position of temperature readings at various depths: 28mm, 20mm, 14mm, 8mm, 3mm, and 1mm. The probe is marked with a symbol indicating its location in the furnace. The furnace dimensions are shown as 74 mm, 54 mm, and 37 mm.
Probe with Temperature Gradient – 72 h Test

Furnace environment

Probe Surface

Channel 1[°C]
Channel 2[°C]
Deposit after 24 h on the Gradient Probe (500/950 C)  
\((\text{Na}_2\text{SO}_4+\text{NaCl})\)
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In-Furnace Data from Large Furnaces

In-Furnace Gas Sampling and Analysis

Analyzers

- **FTIR**
  - NO, NO\textsubscript{2}, NH\textsubscript{3}, HCN, CO\textsubscript{2}, CO, COS, HCl, CS\textsubscript{2}, H\textsubscript{2}O, CH\textsubscript{4}

- **O\textsubscript{2} -analyzer**

- **GC**
  - Reduced sulfur species
    - H\textsubscript{2}S, CH\textsubscript{3}SH, C\textsubscript{2}H\textsubscript{6}S...
Gas Sampling Probes

Length = 4 m
Weight = 70 kg
In-Furnace Gas Sampling Points

Flue gas:
NO $\pm 4$ ppm
NH$_3$ < 1 ppm
Pyroinc 380

- Spectral Filter 3.9 µm
- Temp. Range 400-1500°C
- Temp. Resolution ≤ 1 K
- Field of View 67° x 50°
- Diameter of Probe 104 mm
- IR -2D Array 384 x 288 Pixel
- Frame Rate 50 fps
IR Camera in Black Liquor Furnace
- Liquor sprays under two conditions

Liquor temp. 141.5 °C

138.5 °C

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Aknowledgements

The Research Consortia ”ChemCom” and ”FUSEC”