End Use Performance of Torrefied Biomass in Pulverized Fuel Furnaces and Gasifiers

40th International Technical Conference on Clean Coal & Fuel Systems
May 31 to June 4, 2015
Sheraton Sand Key
Clearwater, Florida, USA

1. C. Ndibe, J. Maier, G. Scheffknecht
2. J. Koppejan
3. S. Leiser, C. Vilela, M. Carbo, J. Kiel
4. A Nordin

1. Institute of Combustion and Power Plant Technology, Universität Stuttgart, 70569-Stuttgart, Germany.
3. Energy Research Center of the Netherlands, P.O. Box 1, 1755 LE Petten, The Netherlands.
4. Umea University, 90187, Umea, Sweden.
Background

- Torrefaction is a slow pyrolysis process that reduces moisture and low energy volatiles in biomass.

- Torrefaction improves handling, storage and milling properties of biomass.

- Cofiring biomass in coal-fired power plants could help meet renewable energy targets on the short term at lower CAPEX.

### Material Properties

<table>
<thead>
<tr>
<th>Material</th>
<th>$\rho_{\text{bulk}}$ (kg/m$^3$)</th>
<th>LHV (MJ/kg)</th>
<th>Hydrophobicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>800</td>
<td>23-28</td>
<td>Hydrophobic</td>
</tr>
<tr>
<td>Torrefied wood pellets</td>
<td>700</td>
<td>18-22</td>
<td>Moderately Hydrophobic</td>
</tr>
<tr>
<td>White wood pellets</td>
<td>550</td>
<td>16-18</td>
<td>Hydrophilic</td>
</tr>
</tbody>
</table>
SECTOR Project Structure (EU Collaborative Project)

SECTOR - Production of Solid Sustainable Energy Carriers from Biomass by Means of Torrefaction

- Assessment of relevant biomass feedstock regarding:
  - Availability now and 2030, incl. price level
  - Suitability for torrefaction and end-use
  - Demands of the end-users

- Optimisation of torrefaction processes regarding the needs of:
  - Densification
  - Logistics
  - End-use

- Optimisation of densification processes for torrefied biomass:
  - Pelletisation
  - Briquetting

- Analysis of fuel properties regarding different possibilities for:
  - Storage
  - Handling
  - Transportation

- Evaluation of the usability of torrefied biomass for:
  - Cofiring in coal plants incl. milling and feeding tests
  - Gasification
  - Small scale combustion
  - Material use

- Demonstration Tests (WP5)
- Torrefaction Process (WP3)
- Densification Process (WP4)
- Logistics (WP6)
- End-Use (WP7)

Specification of material properties and analysis methods (WP8) as well as socio-economics and environmental sustainability analysis of biomass-to-end-use chains (WP9)

e: info@sector-project.eu
w: www.sector-project.eu
TORREFIED BIOMASS IN CONVENTIONAL FIRING SYSTEMS

1. CO-MILLING IN COAL MILLS
2. CHARACTERIZING GRINDABILITY
3. PNEUMATIC FEEDING BEHAVIOR
4. CO-FIRING TESTS
5. CO-GASIFICATION TESTS
6. CONCLUSIONS
CO-MILLING TESTS WITH COAL

Calibrate mill with bituminous coal in medium load (400 kg/h) to fineness analogous to power plant conditions

Stepwise torrefied biomass addition (up to 60 weight-%) at constant throughput

Process parameters: power consumption, pressure loss of the mill and particle size distribution of the product monitored and evaluated

<table>
<thead>
<tr>
<th>Setup</th>
<th>Bituminous coal</th>
<th>Torrefied spruce pellets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Origin: Colombia</td>
<td>Origin Denmark</td>
</tr>
<tr>
<td></td>
<td>Moisture content (%) : 11.7%</td>
<td>2% bark</td>
</tr>
<tr>
<td></td>
<td>Particle size: 4.9% &gt; 20mm</td>
<td>Torr. Temp (°C) : 285</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pellet Dimensions (mm): 40 x 20 x 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moisture content (%) : 7.9</td>
</tr>
<tr>
<td>kg/h</td>
<td>wt-%</td>
<td>energy input-%</td>
</tr>
<tr>
<td>-------</td>
<td>------</td>
<td>---------------</td>
</tr>
<tr>
<td>1</td>
<td>400</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>346</td>
<td>86,5</td>
</tr>
<tr>
<td>3</td>
<td>272</td>
<td>68</td>
</tr>
<tr>
<td>4</td>
<td>166</td>
<td>41,5</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
RESULTS OF CO-MILLING TESTS WITH COAL

- Co-grinding increases fineness compared to separate grinding
- Inevitable energy consumption increase: inhomogeneity
- At 58% Torrefied biomass addition, classifier speed decreased by 25%

![Graph showing grinding energy and cumulative distribution](image-url)

- Torrefied spruce weight % in the comilling mix with Elcer coal
- Co-milling increases fineness compared to separate grinding
- Inevitable energy consumption increase: inhomogeneity
- At 58% Torrefied biomass addition, classifier speed decreased by 25%

![Particle size distribution graph](image-url)

- 13.5% Torr spruce + Elcer
- 32% Torr spruce + Elcer
- 58.5% Torr spruce + Elcer
- Parent size - Torrefied spruce
- Parent size - Elcer coal
- 100% Elcer coal
- 100% Torr spruce
How do we characterize torrefied biomass grindability?

50g [0.63mm; 1.18mm] 60 revolutions (284 N) 75 µm

mass < 75µm – HGI calibrated through 4 reference coals

HGI method fails to characterize torrefied biomass grindability!!
Characterizing biomass grindability

No standard method for biomass, HGI not sufficient even for non standard coals

Adaptation of the HGI


1. Different densities → volume based HGI → constant running bed

2. Sieve requirement. 75µm too fine for biomass! Comparison with coal – different combustion requirements
   - coal : $D_{70} < 75\mu m$ and $D_{99.5} < 300\mu m$
   - biomass: $D_{90} < 1\text{mm}$ and $D_{99.5} < 2\text{mm}$

3. Reference materials!
HGI adaptation

Grindability

HGI / Adapted HGI comparison

Adap HGI = (2 x w%<500µm) -14

Charcoal - 100

- Poplar 300 - 65
- Poplar 280 - 43
- Straw 270 - 39
- Pine 270 - 35
- Wood Pellet - 20

- Reference Coals - HGI
- Biomass HGI
- Reference Materials
- Adapted HGI value
- Linéaire (Reference Coals - HGI)
- Linéaire (Reference Materials)
Torrefied pellet grinding in Hammer mill (200kg/h)

- Grinding energy savings -58-73% for torrefied biomasses compared to white wood pellets
- Finer product distribution – improved combustion efficiency for PF boilers
Pneumatic feeding behavior: coal plants

Dilute phase feeding in industrial boilers:

- Mass loading of coal (kg coal/kg air) = 0.5
- Gas velocity = 19-20 m/s (1.5 times higher than saltation velocity)


Pneumatic conveying phase diagram for pulverised coal (< 100 μm) transported in a 470mm pipe
Pneumatic feeding behavior: lab test conditions

- Particle size distribution of fuels were similar, therefore the transport behaviour must be due to differences in the morphological characteristics!
- Optical microscope observation: coal particles homogeneous and angular, torrefied particles more similar to coal while raw wood particles are very heterogeneous and needle shaped.
Cofiring torrefied biomass at the 500kW furnace
Experimental rig, (KSVA, 500kW<sub>th</sub>)
Measurement locations- I

Measurements performed for every 25mm along the radial axis from level 2 (180mm) to 15 (2670mm)
- Gas specie evolution (O<sub>2</sub>, CO, CO2, NO<sub>x</sub>, SO<sub>2</sub>)
  - Gas temperature profiles
  - Heat flux
- Deposits (cooled and uncooled)
- Flame video monitoring
- Fly ash sampling (burnout)
- Gas concentration measurement at furnace exit
- Fly ash removal by ESP

Staging(OFA) configuration for NO<sub>x</sub> reduction at λ<sub>1</sub> 0,9 and 0,75
Fuel preparation and analysis

![Graph showing cumulative distribution and size distribution of particle size (μm) for El Cerrejon and Torr. Spruce CD.](image1)

<table>
<thead>
<tr>
<th>Torr. Spruce</th>
<th>El Cerejon (hard coal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D10</td>
<td>144</td>
</tr>
<tr>
<td>D50</td>
<td>451</td>
</tr>
<tr>
<td>D90</td>
<td>1168</td>
</tr>
<tr>
<td>Heating Value, (kJ/kg) water free</td>
<td></td>
</tr>
<tr>
<td>H_o</td>
<td>20923</td>
</tr>
<tr>
<td>H_u</td>
<td>19214</td>
</tr>
<tr>
<td>Proximate Analysis (%)</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>2.74</td>
</tr>
<tr>
<td>Ash</td>
<td>0.36</td>
</tr>
<tr>
<td>Volatile (wf)</td>
<td>74.35</td>
</tr>
<tr>
<td>Cfix(waf)</td>
<td>25.65</td>
</tr>
<tr>
<td>Ultimate Analysis, (% water and ash free)</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>54.41</td>
</tr>
<tr>
<td>H_c</td>
<td>6.0</td>
</tr>
<tr>
<td>N</td>
<td>0.20</td>
</tr>
<tr>
<td>S</td>
<td>0.03</td>
</tr>
</tbody>
</table>

![Bar chart showing lab ash oxides (mass %) for SiO2, Al2O3, Fe2O3, MgO, CaO, Na2O, K2O, TiO2, P2O5, and SO3.](image2)
Cofiring coal and torrefied spruce (50%)-  
Measured $O_2$ concentrations in furnace
Cofiring coal and torrefied spruce (50%)-Heat flux and wall temperatures at exit

Higher heat flux and wall temperatures towards furnace exit for configurations involving torrefied spruce!

<table>
<thead>
<tr>
<th>Combusted fuel</th>
<th>Level</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>El Cerrejon</td>
<td>739</td>
<td></td>
</tr>
<tr>
<td>50% Torr spruce + El Cerrejon</td>
<td>754</td>
<td></td>
</tr>
<tr>
<td>Torr Spruce</td>
<td>791</td>
<td></td>
</tr>
</tbody>
</table>
Emissions and unburnt Carbon at furnace outlet

- Higher CO fluctuations during torrefied biomass cases but average levels are lower
- 50% cofiring reduces average NO\textsubscript{X} by 10%
- 100% torrefied spruce decreases NO\textsubscript{X} by 71%

During cofiring, sulphur balance shifts from SO\textsubscript{2} formation to entrainment in ash!

<table>
<thead>
<tr>
<th>Combusted fuel</th>
<th>Unburnt Carbon (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Furnace Outlet</td>
</tr>
<tr>
<td>El Cerrejon</td>
<td>2,00</td>
</tr>
<tr>
<td>50% Torr spruce + El Cerrejon</td>
<td>0,99</td>
</tr>
<tr>
<td>Torr Spruce</td>
<td>0,70</td>
</tr>
</tbody>
</table>
Staged combustion of cofired fuels: Torrefied spruce/El Cerrejon Coal

![Graph showing NOX emissions at 6% exit O2](image)

- El Cerrejon coal
- 50% Torr. Spruce + El Cer.
- Torr. Spruce

In spite of lower emissions during unstaged combustion involving torrefied spruce, air staging will reduce NOX even further!

**OFA addition**

<table>
<thead>
<tr>
<th>Fuels combusted</th>
<th>NOX reduction [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unstaged λ1=1.15</td>
</tr>
<tr>
<td>El Cerrejon coal</td>
<td>0</td>
</tr>
<tr>
<td>50% Torr. Spruce + El Cer.</td>
<td>0</td>
</tr>
<tr>
<td>Torr. Spruce</td>
<td>0</td>
</tr>
</tbody>
</table>
Gasification tests

Lab-scale

1MW Pilot PEFG

Industrial CHP 4.5MW Cyclone EFG

Industrial PEFG (253 MW)

©ECN

©Umea

©Umea

©Vattenfall

©Vattenfall

©Vattenfall

©Vattenfall
Gasification tests-Results summary

- No problems in feeding or process control
- Indication of higher heat flux from the torrefied flame, presumably due to increased flame intensity or larger radiating surface area of the burning fuel particles.
- The syngas H2/CO ratio decreased with the severity of torrefaction.
- Reduced CH4 concentrations in the syngas from severely torrefied fuel
- Indications on higher reactivity of torrefied materials than the reference fuels
- Torrefaction has a significant effect on power consumption for fuel size reduction, which was beneficial for the total plant efficiency, ηplant
Conclusions

- Co-milling Coal/ Torrefied Biomass can be an option for cofiring:
  - Co-grinding increases fineness compared to separate grinding
  - Inevitable energy consumption increase: inhomogeneity

- HGI adapted for characterizing torrefied biomass grindability
  - Adapted HGI validated by fineness and energy consumption criteria

- Issues related to pellet durability during handling still an issue especially dust problems.

- Co-firing/Co-gasification of torrefied biomass at high thermal shares (50% and even 100%) feasible

- Lower SO$_X$ and NO$_X$ emissions
  - In spite of lower emissions, air-staging can still be successfully applied to further reduce NO$_X$ for monofired torrefied biomass or the co-fired cases with coal.
The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 282826 (SECTOR: www.sector-project.eu) and the German Federal Ministry for Economic Affairs and Energy, under agreement number 03ET7012B (Mitverbrennung von Biomasse in kohlebefeuerten Dampfkraftwerken).

Collins Ndibe
Academic Researcher / PhD student
Department of Firing Systems- KWF,
Institute of Combustion and Power Plant Technology,
Uni-Stuttgart – IFK, Germany
✉: collins.ndibe@ifk.uni-stuttgart.de
http://www.ifk.uni-stuttgart.de/