Torrefaction – Process and Product Quality Optimisation

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September 2013
ECN-L--13-056
Torrefaction – Process and Product Quality Optimisation

International VDI Conference – Biomass to Energy

Jaap Kiel
Munich, Germany
3-4 September, 2013

www.ecn.nl
Biomass – major challenge

- Enable decoupling of biomass production and use
  - Place
  - Time
  - Scale

- By converting biomass into high-quality bioenergy carriers (solid, liquid or gas), that:
  - Better fit in (existing) logistic infrastructures
  - Allow efficient, reliable and cost effective conversion into electricity and heat, transport fuels and chemicals

Solve biomass related problems at the source
Torrefaction for upgrading biomass

- **Process parameters**
  - Temperature: 240-320 °C
  - Absence of oxygen

Tenacious and fibrous
LHV = 9 - 12 MJ/kg
Hydrophilic
Biodegradable
Heterogeneous

Friable and less fibrous
LHV = 18 - 24 MJ/kg
Hydrophobic
Preserved
Homogeneous

Pelletisation

Bulk density = 650-800 kg/m$^3$
Bulk energy density = 12 - 19 GJ/m$^3$
# Torrefied biomass properties in perspective

<table>
<thead>
<tr>
<th></th>
<th>Wood chips</th>
<th>Wood pellets</th>
<th>Torrefied wood pellets</th>
<th>Charcoal</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content (wt%)</td>
<td>30 – 55</td>
<td>7 – 10</td>
<td>1 – 5</td>
<td>1 – 5</td>
<td>10 – 15</td>
</tr>
<tr>
<td>Calorific value (LHV, MJ/kg)</td>
<td>7 – 12</td>
<td>15 – 17</td>
<td>18 – 24</td>
<td>30 – 32</td>
<td>23 – 28</td>
</tr>
<tr>
<td>Volatile matter (wt% db)</td>
<td>75 – 85</td>
<td>75 – 85</td>
<td>55 – 80</td>
<td>10 – 12</td>
<td>15 – 30</td>
</tr>
<tr>
<td>Fixed carbon (wt% db)</td>
<td>16 – 25</td>
<td>16 – 25</td>
<td>20 – 40</td>
<td>85 – 87</td>
<td>50 – 55</td>
</tr>
<tr>
<td>Bulk density (kg/l)</td>
<td>0.20 – 0.30</td>
<td>0.55 – 0.65</td>
<td>0.65 – 0.80</td>
<td>0.18 – 0.24</td>
<td>0.80 – 0.85</td>
</tr>
<tr>
<td>Vol. energy density (GJ/m³)</td>
<td>1.4 – 3.6</td>
<td>8 – 11</td>
<td>12 – 19</td>
<td>5.4 – 7.7</td>
<td>18 – 24</td>
</tr>
<tr>
<td>Hygroscopic properties</td>
<td>Hydrophilic</td>
<td>Hydrophilic</td>
<td>(Moderately) Hydrophobic</td>
<td>Hydrophobic</td>
<td>Hydrophobic</td>
</tr>
<tr>
<td>Biological degradation</td>
<td>Fast</td>
<td>Moderate</td>
<td>Slow</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Milling requirements</td>
<td>Special</td>
<td>Special</td>
<td>Standard</td>
<td>Standard</td>
<td>Standard</td>
</tr>
<tr>
<td>Product consistency</td>
<td>Limited</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Transport cost</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
</tr>
</tbody>
</table>

Abbreviations:
db = dry basis
LHV = Lower Heating Value

sources: ECN (table, fig. 1, 3), Pixelio (fig. 2, 5), ofi (fig. 4)
The added value of torrefaction

- Torrefaction (+ densification) enables energy-efficient (>90%) upgrading of biomass into *commodity solid biofuels* with favourable properties in view of logistics and end-use.

- Favourable properties include high energy density, better water resistance, slower biodegradation, good grindability, good “flowability”, homogenised material properties.

- Therefore, cost savings in handling and transport, advanced trading schemes (futures) possible, capex savings at end-user (e.g. outside storage, direct co-milling and co-feeding), higher co-firing percentages and enabling technology for gasification-based biofuels and biochemicals production.

- Applicable to a wide range of lignocellulosic biomass feedstock, even mixed waste streams.
Torrefaction – development status

- Many technology developers (>50) due to strong market pull
- Often application of reactor technology proven for other applications (drying, pyrolysis, combustion)
- Good process control is essential for good performance and product quality control (temperature, residence time, mixing, condensables in torrefaction gas)
- High energy efficiency is crucial in view of overall cost and sustainability; overall energy efficiency is strongly dependent on heat integration design
- In general: torrefaction technology in demonstration phase with >10 demo-units and first commercial units in operation and under construction
ECN and torrefaction

- >20 years experience in biomass co-firing R&D, identified the potential of torrefaction and played a pioneering role in adapting torrefaction to bioenergy applications since 2002

- ECN’s torrefaction technology proven on industrial scale and together with Andritz now taken to commercial market introduction

- R&D (EU/NL-funded projects and industrial contracts) to optimise product quality, assess the torrefaction potential of specific feedstock and produce test batches

ECN 50 kg/h torrefaction pilot-plant
**Two Main Technology Platforms**

<table>
<thead>
<tr>
<th>Large plants: up to 700,000 t/a per line</th>
<th>Small / medium plants: 50,000-250,000 t/a</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Andritz/ECN Torrefaction Design</strong></td>
<td><strong>Andritz ACB® Torrefaction Design</strong></td>
</tr>
<tr>
<td>Industrial Demoplant (1t/h) in Denmark started up in 3rd quarter 2012</td>
<td>Industrial Demoplant (1t/h) in Austria in operation from 4th quarter 2011.</td>
</tr>
<tr>
<td>Pressurized, moving bed reactor Andritz/DTI Pelleting plant</td>
<td>Rotating, indirectly heated drum reactor Briquetting plant</td>
</tr>
</tbody>
</table>

**Key Features:**
- Andritz/ECN Torrefaction Design:
  - Scale up to huge capacities possible (experience from Pulp & Paper)
  - Feed material: Wood Chips/Forest Residuals

- Andritz ACB® Torrefaction Design:
  - Simple process concept specially developed for decentralized plants
  - Flexibility in feed material
Andritz ACB® process
Small capacity reactor systems for 50,000 t/a per line

- Rotating, indirectly heated drum
- Prevention of condensation problems due to gas flow pattern
- Flexibility in terms of allowable particle size
- No clogging, channeling or increase in pressure drop
- Oxygen infiltration avoided by drum sealing technology
- Construction based on proven Drum Drying System (> 110 such dryers worldwide)

Demo plant for production of 1 t/hr of torrefied briquettes installed in Frohnleiten, Austria
Andritz has built a 1 ton/hour torrefaction demo plant in Sdr. Stenderup, Denmark.

The plant incorporates:
- Biomass (wood chip) receiving
- Biomass drying
- Torrefaction
- Pelletizing

The plant entered commissioning in the 2nd quarter of 2012 and is currently fully operational.

The project is partially funded by the Danish EUDP (Energy Technology Development and Demonstration Programme) with a significant majority of the capital funding from Andritz.

The Danish Technology Institute (DTI), and energy companies Drax and Dong are involved as part of the EUDP team.

The Energy research Centre of the Netherlands (ECN) is acting as a consultant to Andritz on the design of the torrefaction technology and is involved in the commissioning and optimisation of the demo plant.
Sdr. Stenderup demo plant
Capacity 1 t/hr biomass input (db)

- The torrefaction system:
  - Blends ECN and Andritz technologies (patents granted and pending)
  - Pressurised for more effective heat transfer due to higher gas flows, lower velocities and pressure drop for increased capacity
  - Provides a separation between the final drying zone and the beginning of torrefaction
  - Includes a co-current torrefaction zone
  - Lends itself to scale up to large single unit capacities
    - High fraction of the vessel volume is used for either final drying or torrefaction
    - The capacity will increase as the diameter squared
Sdr. Stenderup demo plant
Simplified single line flow sheet

ATEX Analysis was done on entire system and multiple design changes made.

Patents granted and Pending
ECN/Andritz pressurised reactor concept

- Wood Chips In (~8-10%)
- Drying Gas In
- Drying Gas Out to Heating
- Hot Torrefaction Gas In
- Torrefaction Gas Out to Gas Cleaning and Heating
- Hot Torrefaction Gas In
- Torrefied Wood Out

Patents Granted and Pending
Sdr. Stenderup demo plant
Capacity 1 t/hr biomass input (db)
Status
Ready for market introduction

- The demo plant is in operation and producing product for test firings and optimisation
- Andritz is in the process of discussing commercial scale systems
- Andritz is pleased to discuss your requirements
Product quality optimisation

- Pilot, demo and first commercial plants produce tonne-scale batches allowing representative logistics and end-use performance testing by industry.

- Product quality optimisation requires a systematic, iterative approach (2 iterative loops).

- For this purpose, European torrefaction developers, combustion and gasification technology providers and end-users have joined forces in the EU-FP7 project SECTOR.

- + NL project Pretreatment, with involvement of Topell, Torr Coal, Biolake, Essent, NUON, GdF Suez, TU Delft, U Twente, ECN.
Impact of torrefaction degree

- Densification
- Self-heating
- Dust explosion
- Water uptake / leachability
- Grindability
- Heating value
- Reactivity
- Cost / Sustainability
- .......

Indicative trends
SECTOR
Production of Solid Sustainable Energy Carriers from Biomass by means of Torrefaction

- Collaborative project: SECTOR
- Project start: 01.01.2012
- Duration: 42 months
- Total budget: 10 MEuro
- Participants: 21 from 9 EU-countries (+ industrial advisory group)
- Coordinator: DBFZ (supported by ECN, ofi)

www.sector-project.eu
SECTOR
Objectives

• **Support the market introduction** of torrefaction-based bioenergy carriers

• **Further development of torrefaction**-based technologies

• **Development of specific production recipes**, validated through extensive lab-to-industrial-scale logistics and end-use performance testing

• Development and standardisation of dedicated **analysis and testing methods** for assessment of transport, storage, handling logistics and end-use performance (+** product standards, MSDS, REACH**)

• Assessment of the role of torrefaction-based solid bioenergy carriers in the bioenergy **value chains**

• **Full sustainability assessment** of the major torrefaction-based biomass-to-end-use value chains

• **Dissemination** of project results to industry and into international forums (e.g. CEN/ISO, IEA and sustainability round tables)
SECTOR
Project structure

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

Specification of material properties and analysis methods (WP8) as well as socio-economics and environmental sustainability analysis of biomass-to-end-use chains (WP9)
**SECTOR - Cereal straw torrefaction (CENER)**

**Mass and energy balance at autothermal conditions**

- **Biomass: Straw**
  - Torrefaction degree (daf): 16%

- **Natural gas**
  - 76 kW

- **Biomass for Torrefaction**
  - 3.650 kg/h
  - 12% moisture
  - 15.1 MJ/kg as received
  - 15.295 kW

- **Net thermal efficiency**:
  - 95.1%
  - % of mass in product: 74.7%

- **120°C**
  - 149 kW
  - 5.364 kg/h
  - Torrgas

- **Net thermal efficiency**:
  - 95.1%
  - % of mass in product: 74.7%

- **Torrefied biomass**
  - 2.725 kg/h
  - 19.3 MJ/kg
  - 14.626 kW

- **Product cooling**
  - 224 kW

- **Heat losses (total)**
  - 373 kW
  - **Torrefaction**: 321 kW
  - **Thermal oxidiser**: 20 kW
  - **Bioler**: 23 kW
  - **Air preheater**: 9 kW

- **Higher efficiency than woody biomass torrefaction due to the lower moisture content and higher reactivity (lower torrefaction temperature for straw)**
**SECTOR**

Round Robin for torrefied wood pellets analyses (OFI)

Samples shipment July 2012

- 45 Registrations
- 43 Participants
- 18 Countries
- 11 Parameter (19-41 participants per parameter)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Method/ Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk density</td>
<td>acc. EN 15103</td>
</tr>
<tr>
<td>Mechanical durability</td>
<td>acc. EN 15210-1</td>
</tr>
<tr>
<td>Moisture content</td>
<td>acc. EN 14774-1 or 2</td>
</tr>
<tr>
<td>Ash content</td>
<td>acc. EN 14775</td>
</tr>
<tr>
<td>Calorific value</td>
<td>acc. EN 14918</td>
</tr>
<tr>
<td>Content of chlorine and sulphur</td>
<td>acc. EN 15289</td>
</tr>
<tr>
<td>Content of volatile matter</td>
<td>acc. EN 15148</td>
</tr>
<tr>
<td>Content of carbon, hydrogen, nitrogen</td>
<td>acc. EN 15104</td>
</tr>
<tr>
<td>Content of major elements</td>
<td>acc. EN 15290</td>
</tr>
<tr>
<td>Content of minor elements</td>
<td>acc. EN 15297</td>
</tr>
<tr>
<td>Ash melting behaviour</td>
<td>acc. CEN/TS 15370</td>
</tr>
</tbody>
</table>

For details see Deliverable 8.1: [http://www.sector-project.eu/results.5.0.html](http://www.sector-project.eu/results.5.0.html)
SECTOR
Round Robin – comparison of analysis method precision to biomass samples

For details see Deliverable 8.1: http://www.sector-project.eu/results.5.0.html
SECTOR
Round Robin – conclusions

• Most of the standardised solid biofuels test methods are applicable without any adoption for torrefied material, e.g.:
  – Ash content analysis (EN 14775)
  – Moisture content analysis (EN 14774-1 and 2)
  – Chlorine and Sulphur content analysis (EN 15289)
  – CHN analysis (EN 15104)

• For the following ISO standards
  – ISO/DIS 16948-Carbon, Hydrogen and Nitrogen content
  – 16968-Minor element
  – 16967-Major elements
  – 16994-Sulphur and Chlorine content
torrefied material would be added without any modification.

• The results of these round robin results will be added to the existing performance characteristics tables

• SECTOR partners participate in the standard development: new proposed standard ISO 17225-x: "Solid biofuels - Fuel specifications and classes - Graded thermally treated densified biomass"
SECTOR
Development of new analysis methods

List of analysis methods to be developed until 2014/2015:

- NIR spectroscopy
- TGA method
- Leaching behaviour
- Hydrophobicity- water absorption
- Degree of torrefaction
- Grindability
- Particle size distribution and size distribution and flowability properties
SECTOR
Pneumatic transport behaviour

- All materials milled with similar power consumption
- Milled pellets, mean particle size 200-350 μm
- Ambient air as carrier gas
- Ground fresh wood does not flow at all
- Torrefied materials flow well
- Flow properties closely related to feedstock, less to torrefaction temperature
SECTOR
Particle shape after milling

Spruce 240°C
Spruce 260°C
Spruce 280°C
Coal
Poplar 265°C
Self-heating
Experimental approach

- Adiabatic reactor set-up to simulate stock-piles and storage silos
- Materials are fed pre-dried in the reactor in order to investigate the impact of water uptake
- Reactor is gently purged with air/water vapor or N\textsubscript{2}/water vapor mixtures
- Runs with nitrogen are used as reference cases (zero-measurement)
Self-heating
Raw and torrefied biomass (preliminary results)

![Graph showing the relationship between bed temperature and time for different biomass samples. The graph indicates the variations in water uptake and oxidation for raw and torrefied wood, as well as torrefied pellets.](image-url)
Self-heating
Softwood chips, moist air (improved reactor control)

Tests with torrefied chips and torrefied pellets are in progress
December 2012: AEBIOM and the torrefied biomass stakeholders decided to join forces and create the **International Biomass Torrefaction Council (IBTC)** as a discussion platform among companies with similar interests.

**IBTC objectives**
- Promote the use of torrefied biomass as energy carrier
- Help overcoming the barriers to market deployment
- Express the views of torrefaction industry to the general public and propose and assist policy initiatives
- Support and participation in initiatives and projects dedicated to biomass torrefaction market development such as: collection of statistical data, standardization issues, certification of and permissions for the product, communication initiatives, matters related to health and safety.

More info: [www.aebiom.org](http://www.aebiom.org) > Networks
Contact IBTC at calderon@aebiom.org
IBTC members – June 2013

IBTC Full Members

KAHL, ANDRITZ, AREVA, BIOLAKE, CMI, Electrabel, RIVER BASIN ENERGY INC, Rotawave, VATTENFALL, Topell Energy, TORR COAL

IBTC Supporting Members

ECN, energy valley, DNV, KEMA
Summary

• Torrefaction potentially allows cost-effective production of commodity solid biofuels from a wide range of biomass/waste feedstock with a high energy efficiency (>90%) allowing a decoupling of biomass production and use

• Torrefaction development is in the pilot/demo-phase, with >10 demo initiatives underway in Europe; the two Andritz torrefaction technologies are ready for market introduction

• Main characteristics of torrefaction are known, but performance testing, iterative optimisation of production recipes and product standardisation require further efforts

• The EU-SECTOR project is focused on this to facilitate commercial market introduction of torrefaction technology and torrefied products (www.sector-project.eu)
Thank you for your attention!

Special thanks to:
- Colleagues at ECN, Andritz and partners in the SECTOR project (in particular DBFZ, CENER, OFI)
- NL Min. of Economic Affairs, Andritz, EUDP partners, SECTOR partners and EU for providing financial support

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The research in the SECTOR project has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 282826