Volatile Yields and Solid Grindability after Torrefaction of Various Biomass Types

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1. INTRODUCTION

The process: from biomass to fuel

Lignocellulosic Biomass

Collection → Pretreatment → Gasification → Post-treatment → Synthesis

• Grinding
• Drying
• Pyrolysis
• Pelletization

Torrefaction

High feedstock variability

Crucial issue for process industrialization!

Suitability feedstock / process?

2. PRODUCTS YIELDS

Grinding
Pyrolysis
Torrefaction

Syngas (H₂, CO)

• Liquid fuel (Diesel Fischer-Tropsch, methanol)
• Gaseous fuel (SNG, H₂)

3. SOLID GRINDABILITY

4. CONCLUSION
Biomass torrefaction

- Smooth thermal transformation under inert atmosphere
  - Between drying and pyrolysis
  - \( T = 200-300^\circ C \)
  - Residence time = 15 min – several hours
  - Atmospheric pressure

**Biomass** 
\( \text{C}_6\text{H}_9\text{O}_4 \) + moisture~20%

**Torrefied biomass** 
\( \text{C}_6\text{H}_8\text{O}_3 \) + moisture~3%

**Volatile matter:**
- Gas (CO, CO\(_2\))
- Condensable species (H\(_2\)O, acids...)

- Solid properties get more coal-like
  - Decrease of H/C and O/C
  - Hydrophobic nature
  - Higher energy content
  - Improved grindability and powder flowability

Suitable for entrained flow gasification
Biomasses

- Pine
- Miscanthus
- Wheat straw
- Poplar

> Sampling according to XP CENT/TS 14786
> Grinding ≈ cm

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Proximate analysis (wt. %)</th>
<th>Ultimate analysis (wt. % daf)</th>
<th>LHV (MJ/kg db)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moisture</td>
<td>Ash (db)</td>
<td>VM (db)</td>
</tr>
<tr>
<td>Pine</td>
<td>11.9</td>
<td>0.3</td>
<td>85.2</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>8.2</td>
<td>2.2</td>
<td>80.9</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>9.0</td>
<td>6.4</td>
<td>73.5</td>
</tr>
<tr>
<td>Poplar</td>
<td>9.0</td>
<td>3.4</td>
<td>81.0</td>
</tr>
</tbody>
</table>
Objective and working plan

Objective:

Characterization of products released during torrefaction of various biomass nature:

- Products mass balance
- Solid grindability

Working plan:

- Torrefaction experiments in lab-scale reactor
- Grindability tests on raw and torrefied biomasses
Lab-scale tests: Products mass balance
The lab-scale device ALIGATOR

> Samples dried at 105°C according to XP CEN/TS 14774
Global mass balance

- Global distribution depends on nature of biomass
  - Higher mass loss for agricultural by-products and SRC
- For all biomass types: Volatile species are mainly condensable

Closure: 95 - 100%
Mass balance: Volatile species

- Water and dry condensable: difference softwood/agricultural biomass
- CO: high content for agricultural by-products
  - Litt: \( \text{CO}_2 \leq \text{decarboxylation of acid groups} \)
  - CO: Not clearly explained; catalytic reaction between CO2 and C?
Mass balance: Volatile species

- CO/gas ratio increases with ash content
- Mineral matter catalytic effect
Mass balance: dry condensable species

Impact on torrefaction cleaning step!

Closure: 33 - 66%

- Acetic acid ~50% except for softwood (~ 20%)
- Formaldehyde and glycolaldehyde not in wheat straw
- Propionic acid only in pine and wheat straw
- Furanmethanol not in pine
- Propanone high in wheat straw and absent in poplar
- Furfural in all biomasses
• Ratios H/C and O/C are similar for all raw biomasses, except for poplar
• Torrefied solids have lower ratios than raw biomasses
Torrefied solid: energy yield

Energy yield (%) = \( \frac{M_f \times GCV_f}{M_0 \times GCV_0} \times 100 \) (Arias, 2008)

- LHV similar for raw biomasses; LHV increases after torrefaction
- Highest energy yield for pine
Grindability tests
Grinding device

- Ball mill
- Protocol
  - volume of biomass: 50 cm³
  - grinding time: 1 min

Particle size distribution

- Sieving following standard NF EN 15149
- Low weight sieves of \( \phi = 60 \text{mm} \)
  - 6 sieves from 1mm to 50µm
Torrefaction protocol

Objective:
To assess influence of nature of biomass on grindability

⇒ mass loss ~ 17% for all biomasses

⇓ Adjustment of torrefaction temperature

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Torrefaction temp. (°C)</th>
<th>Mass loss (wt. %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pine</td>
<td>275</td>
<td>17.0</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>250</td>
<td>16.9</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>240</td>
<td>17.2</td>
</tr>
<tr>
<td>Poplar</td>
<td>245</td>
<td>17.6</td>
</tr>
</tbody>
</table>

Relative grinding energy

Assumptions:
- Proportional to surface created
- Particles are spherical
- Same density whatever particle size

Relative grinding energy = \( \frac{1}{\text{Cumulative mass fraction}} \)
Particle size distribution

- Smaller particle sizes after torrefaction than raw biomass
- Large fraction of torrefied particles suitable to gasification

Typical process particle size

Cumulative particle size distribution (%)

- Raw Pine
- Raw Miscanthus
- Raw Wheat Straw
- Raw poplar
- Torrefied Pine
- Torrefied Miscanthus
- Torrefied Wheat Straw
- Torrefied poplar
Relative grinding energy

Typical process particle size

- Raw Pine
- Raw Miscanthus
- Raw Wheat straw
- Raw Poplar
- Torrefied Pine
- Torrefied Miscanthus
- Torrefied Wheat straw
- Torrefied Poplar

- Torrefaction: energy ↓ by factor 2-3 at 300µm except for wheat straw (1.4)
Conclusion

Properties of products released during torrefaction of various biomasses?

• Torrefaction improves biomass grindability:
  ➢ Grinding energy significantly reduced by torrefaction
  ➢ Trend less marked for wheat straw
    😊 Pine, Miscanthus, SRC 😞 Wheat straw

• Gaseous products composition depends on nature of biomass
  ➢ To be considered for cleaning step
  ➢ Interesting for species valorization in biorefinery process
    😊 All biomasses???
    ⇔ depend on nature of the relevant species for chemical valorization

What’s next?

• Tests on other samples
• Pilot scale tests ⇔ continuous torrefaction
• Comparison of grindability tests with measures on grinding energy at large scale
• Improvement of condensable species quantification
If you have any questions or want more details, please contact:
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