Microwave treatment of biomass

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York
One of Europe’s most beautiful and historic cities.
Excellence and innovation in Green Chemistry research across the bio-based economy.

Pre-treatment and extraction → Bulk components → Conversion and separation technologies → Clean chemical synthesis → Application testing

Materials Substitution: Biobased polymers

Biomass to Chemicals: Microwave, Catalysis and Flow (EPSRC)

End-of-life evaluation → Scale-up

KBBPPS: Pre-Standardization Research for Bio-based Products

Biorenewables Development Centre
**Byproduct problem:**
*World Biomass Residues: >1 bn t/yr & ££££*

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**Legislation**
- 20% renewable fuel by 2020 (EU)
- 30% renewables by 2030 (US)

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**Microwave technology**
- Low temperature
- Energy efficient
- Any biomass
- Zero-waste
- Scalable

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**Market**
- Desire for Bio-based
Why microwaves?

- Rapid internal heating
- Uniform heating
- Instant control
- Acceleration of reaction rate
- Selective interaction with active groups
Versatile platform technology with two key approaches:

**Pyrolysis**
Microwave treatment under inert atmosphere (140 – 300 °C)

Key benefits:
- All biomass
- One-step formation of biofuels
- *In-situ* fractionation → low-acidity stable bio-naptha
- Target biomass components

**Char for Gasification**

**Hydrothermal**
Microwave treatment in water (100 – 260 °C)

Key benefits:
- All biomass, especially wet
- Hydrolysis of polysaccharides to fermentable sugars
- Extraction of polysaccharides (e.g. pectin)

**Fermentation pretreatment**
Microwave Pyrolysis Treatment of Biomass

- Biomass
- Energy
- Microwave processor
  - Extracted oil
  - Pyrolysis Oil
  - Char

Wide range of feedstock + Flexibility of Microwave Parameters (time, temperature, power) = Wide range of products
Microwave pyrolysis

Microwave results in pyrolysis at lower temperature for all biomass and biomass components studied → reduced energy

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Temperature of Microwave decomposition, °C</th>
<th>Temperature of Conventional decomposition °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemicellulose</td>
<td>160</td>
<td>280</td>
</tr>
<tr>
<td>Cellulose</td>
<td>180</td>
<td>320</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>160</td>
<td>341</td>
</tr>
<tr>
<td>Wood</td>
<td>164</td>
<td>371</td>
</tr>
<tr>
<td>Paper</td>
<td>200</td>
<td>420</td>
</tr>
</tbody>
</table>
MW pyrolysis enables in-situ bio-oil separation

- Applicable to wide range of biomass including wood, paper, sugarcane bagasse, seaweed, wheat straw, barley dust.
- In-situ fractionation to valuable products:
  - Fraction 2 (acid, water) source of acids for bio-surfactants
  - Fraction 4 (sugars) basis for platform molecules
  - Fractions 3 & 5 (Phenols, furans) drop-in replacements for petrochemical industry
Characteristics of MW Bio-Char

- High calorific value
  \(~30\text{kJ/g}\)
- Good grindability
- Good hydrophobicity
- Co-firing with coal
- Ideal for gasification
Semi-scale microwave trials (30 kg/h)

12 trials
5 types of biomass
Temperature: 110°-190°C

18 kg of wheat straw

6.7 kg of char + 5.7 kg of oil
Benefit of Microwave Hydrolysis

- High efficiency of heating: water is the best microwave absorber
- Saving energy of water vaporisation
- Direct solubilisation of biomass due to hydrolysis of polysaccharides
Bio-Waste

Acid Hydrolysis

Microwave technology

Problems:
✓ Salt Waste
✓ Low value Lignin
✓ Corrosion/Safety

Faster, energy efficient

Sugars

Fermentation

Existing market

Fuels
- Bio-ethanol (£4bn)
- Butanol (£3.6bn)
Polymer
- Succinic acid (£0.7bn)
Food
- Lactic acid (£2.7bn)
- Citric acid (£3.5bn)

Benefits:
✓ Acid free
✓ Waste agnostic
✓ Tunability
✓ Specific activation

Additional products & market opportunity
- Wax (>£3.0bn)
- Limonene (>0.2bn)
- Phenols (£2.4 bn)
- HMF (1.5MT)
- Levoglucosenone (?)
Microwave Assisted Cellulose Hydrolysis

- Sugars yield increases x20 in the presence of microwave irradiation
- High selectivity toward glucose. Repeated MW hydrolysis of solid produces up to 40% yield of sugars at 220°C

Fan et al, JACS, 2013, 1178
Continuous microwave processor. 30 kg/h

Getting ready for the large scale!

Extending to pressurised reactors
Green Chemistry
Centre of Excellence

www.greenchemistry.net
MW as a heater

Continuous electric current:
• Continuous electric current of dipole is impossible

Alternative electric current (dipolar polarization mechanism):
• Inversion of orientation at every alternance
• Stirring and friction of molecule
• Internal homogeneous heating

Alternative electric current of ions (conduction mechanism):
• Debye effect: If $v > 109$ resistance decrease dramatically