Unravel the structure and reactivity of wood and biowaste biochars

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Research field: Alternative feedstocks to energy and multifunctional materials

My group: 16 persons (4 faculties + 8 PhDs and 4 post-docs)

Combustion (750-1000 °C; Excess air)

Pyrolysis (400 – 800 °C; Inert atm)

Gasification (>800 °C; Atm: αO₂, H₂O,CO₂)

Steam reforming

Gas

CO₂ + H₂O, (∆Hr)

CH₄ + H₂O → CO + 3 H₂

Biochar

Syngas (CO, H₂)

H₂ + HCl, Metals

CH₄ + H₂O → CO + 3 H₂

CHP

Electricity

Fuel cell

H₂

Heat

Cleaning and/or separation

Catalytic synthesis

Biocommodities, MeOH, EtOH & Fuels

Refinery

Multi-functional materials for:
• Environment
• Composites
• Energy
• Chemistry
• Agronomy

Wood

Biomass, Waste

MSW (Municipal Solid Waste)

Food Waste

RDF (Refuse Derived Fuel)

SRF (Solid Recovered Fuel)

Paper, plastic, chips of wood

C&IW (Commercial & Industrial Waste)
I. Biochar production and utilisation

II. Biochar characterisation and properties

III. Some applications as ceramics for environmental remediation

IV. To take home
I. Biochar production and utilisation

Thermochemical conversion – range of applications

100 - 150°C
Drying
A dehydration with the release of light hydrocarbons

250 - 280°C
Torrefaction
A mild form of pyrolysis dedicated only for biomass conversion. Torrefaction leads to obtaining dry product with higher energy content. Main product is biocoal - yield between 70 and 80%

300 - 550°C
MT pyrolysis
Enables chemical conversion of products like biomass, plastic, or rubber into a solid, liquid or gas phase. Enables valorization to biooil and biochar. Yield of biooil ranges from 30 to 60%. Yield of biochar 25 to 35%

600 - 900°C
HT pyrolysis & gasification
Conversion most of the feedstock into methane-rich syngas which can be valorized into energy by using it CHP unit or steam boiler. Yield of syngas ranges from 50 and 95%

ΔH_v(H_2O) = 2.3 MJ/kg at 100°C

LHV (Low heating value): 8 < Biocoal (MJ/kg) < 22
13 < Biooil (MJ/kg) < 27
10 < Biochar (MJ/kg) < 32
12 < Syngas (MJ/kg) < 20

Reference: LHV H_2= 120 MJ/kg LHV CH_4= 50 MJ/kg LHV MSW=10 MJ/kg
Energy
- Fuel cells
- Photovoltaic
- Supercapacitors

Chemistry
- Catalyst
- Adsorbent
- Water treatment

Environment
- Carbon sequestration
- CO₂ Storage
- Sensors

Agronomy
- Water retention
- Plant nutrients
- Soil conditioner

Composites
- Reinforcing materials in polymer composites.
- Biocomposites

Other uses
- Biomedical use
- Pharmaceutical

I. Biochar production and utilisation

Some current utilisations
I. Biochar production and utilisation

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II. Biochar characterisation and properties

Raw biomass composition

Three tropical biomasses were selected from different agro wastes:

- Oil Palm Shell (OPS)
- Coconut Shell (CS)
- Bamboo (BG)

Inorganic composition

Macromolecular composition

- Oil palm shells and Coconut shells are endocarps with high lignin content
- Si is the most important inorganic constituent of Bamboo guadua
- K is the most important inorganic constituent of Coconut shells
II. Biochar characterisation and properties

Chemical properties
- carbon matrix
  - Raman spectroscopy → *Carbon structure distribution*
  - Transmission Electron Microscopy (TEM)
  - X-Ray Tomography → *Nanostructure*
- O- groups
  - Fourier transformed infrared (FTIR) → *Nature of O-containing groups*
  - Temperature Programmed Desorption (TPD) → *Quantification*
- minerals
  - X-ray fluorescence (XRF) → *Elemental analysis*
  - X-ray diffraction (XRD) → *Structure*
  - ESEM analysis → *Distribution*

Physical properties
- textural properties
  - BET analysis → *Specific surface area*
  - Porosity
II. Biochar characterisation and properties

- Raw biochar **complex carbon** containing:
  - Ordered structure
  - Disordered structure

Raman spectrum

Disordered structure

*Mean pore diam: 0.7 nm*

GAK_SB2_850°C

High Resolution TEM spectra

Turbostratic structure

Graphite structure
II. Biochar characterisation and properties

BIOCHAR 700°C

HRTEM

Porosity

Graphene fringes
II. Biochar characterisation and properties

BIOCHAR 400°C

Bright field TEM - nanopores
II. Biochar characterisation and properties

Surface functions determination

- **Strong acids**
  - Carboxylic acid
  - Phenol

- **Weak acids**
  - Anhydride acid
  - Lactone
  - Quinone
  - Pyrone

- **Bases**

**Temperature Programmed Desorption (TPD):**
- TPX (R, O, D)
- TPR: reductible species
- TPO: oxidable species
- TPD: active sites
- Chimisorption: dispersion of metals
- Titration: acidic and basic sites

II. Biochar characterisation and properties

Surface functions determination

Temperature Programmed Desorption (TPD) - Gas chromatography

Biochar from poplar wood

Concentration (%) vs. Temperature (°C)

Strong acids  Weak acids  Bases

CO₂  anhydride acid  lactone

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III. Some applications as ceramics for environmental remediation

Clay biochar Composites

- Filters for polluted gas
- Filters for effluents treatment
- Sensors for pollutants removal

![Graph showing Specific surface area vs Addition rate for Clay + Biochar]
Wastewater treatment: Denitrification

<table>
<thead>
<tr>
<th>Sample</th>
<th>Total porosity (%)</th>
<th>Open porosity (vol.%)</th>
<th>Permeability (mD)</th>
<th>Specific surface area (m²/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CWF</td>
<td>34</td>
<td>27</td>
<td>23</td>
<td>0.9</td>
</tr>
<tr>
<td>CWF + 20 wt.% biochar</td>
<td>57</td>
<td>52</td>
<td>43</td>
<td>194.7</td>
</tr>
</tbody>
</table>

Data obtained using water absorption (porosity), mercury intrusion porosimetry (permeability) and nitrogen adsorption analysis using the BET method (specific surface area)

Contaminants (nitrate), adhesion forces and capture efficiency of the ceramic water filter (CWF).

Data obtained using chromatography (IC) and inductively coupled plasma mass spectrometry (ICP-MS)

P.M. Nigay et al. J. of Environ. Eng., 2017
III. Some applications as ceramics for environmental remediation

Wastewater treatment: Removal of heavy metals

Dependence of the cadmium capture efficiency of the clay ceramic

![Graph showing cadmium capture efficiency for different compositions of clay ceramic and biochar additives.](image-url)
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✓ Carbonaceous materials such as biochar can derive from renewable resources such as Biomass and Biogenic waste

✓ Can be used as a product itself or as an ingredient within a blended product, with a range of potential applications as ceramics

✓ Renewable nature
✓ Cost effectiveness
✓ Tunable: reactivity, thermal and mechanical stability
✓ Well adapted for developing Countries

BIOCHAR: A tunable and multi-functional material
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