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)
- 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)

Pyrolysis (400 – 800 °C; Inert atm)
- Wood
- Biomass, Waste
- MSW (Municipal Solid Waste)
- Food Waste

Gas
- CH₄ + H₂O → CO + 3 H₂

Steam reforming

Biochar

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

Syngas (CO, H₂)
- Cleaning and/or separation
- H₂
- HCl, Metals
- Catalytic synthesis

CH₄ + H₂O → CO + 3 H₂

Syngas (CO, H₂)

CHP

Electricity

Heat

Fuel cell

Refinery

Bio-Oil / Tar

Multi-functional materials for:
- Environment
- Composites
- Energy
- Chemistry
- Agronomy
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%.

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%

Yield of biochar 25 to 35%

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

Reference: LHV H2= 120 MJ/kg LHV CH4= 50 MJ/kg LHV MSW=10 MJ/kg

\[ \Delta H_v(H_2O) = 2.3 \text{ MJ/kg at 100°C} \]
I. Biochar production and utilisation

Some current utilisations

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

Carbon fibers
Nanotubes
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

- 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
II. Biochar characterisation and properties

BG- BIOCHAR 750°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

- CO$_2$
- anhydride acid
- peroxide
- lactone
- carboxylic acid

- CO
- phenol
- hydroxyl
- quinone
- anhydride acid
- pyrone
- ether

Strong acids  Weak acids  Bases

III. Some applications as ceramics for environmental remediation

Clay biochar Composites

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

![Image of filter with polluted gas]

![Graph showing specific surface area vs. addition rate for Clay + Biochar and Wood biochar-750°C]
III. Some applications as ceramics for environmental remediation

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>
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<tbody>
<tr>
<td>CWF</td>
<td>34</td>
<td>27</td>
<td>23</td>
<td>0.9</td>
</tr>
<tr>
<td>CWF+ 20wt.% 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 AFM, chromatography (IC), 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 the dependence of cadmium capture efficiency on the amount of biochar added to the clay ceramic.](image-url)
IV. To take home

- 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
Thank you to my research group and international colleagues:

Thank you to Maria and Kostas for the invitation and for the PARTICULAR CARE.