CO$_2$ capture using biomass-derived activated carbons

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Presentation Outline

• Introduction
• Research Objectives
• Materials and Methods
• Results
• Conclusions
• Acknowledgement
Introduction

Carbon dioxide emissions reduction: Emerging Technologies

Source: Olivier Le Moal/Shutterstock® (2019)

Source: CO2CRC
Research Themes

- Synthesis and characterization of activated carbons made from date seeds biomass in the United Arab Emirates (UAE), and evaluating viability as solid adsorbent for CO$_2$ capture

- **RICH Center- Khalifa University Abu Dhabi:**
  Long-term project on developing alternative inexpensive sorbent materials for carbon dioxide capture and energy storage purposes, documenting optimal experimental synthesis procedures and molecular simulations, and examining performance at industrial conditions.
Materials

UAE Date fruit- seeds

- Excellent natural structure, lignocellulosic composition and low ash content\(^1\)
- Widely consumed in the UAE and Middle East, and seed residues mostly discarded
- Proven suitability for activated carbon synthesis but potentials for CO\(_2\) capture not yet explored\(^1\)

Methods (1)

Physical Synthesis

- Pyrolysis Temperature: 600, 700, 800, 900°C
- Uniform pyrolysis time (1 hour), varying activation times (0.75H, 1H, 2H, 3H)
- **Determination of optimaums**: Yield, Pyrolysis temp, Activation time
Methods (2)

Chemical Synthesis

- **Pyrolysis & activation Temperature**: 600, 700, 800, 900°C
- Determination of optimum impregnation ratio (0.5:1, 1:1, 2:1)

\[
\text{Impregnation Ratio (IR)} = \frac{\text{Mass of Activating Agent (g)}}{\text{Mass of CDS (g)}}
\]
## Methods (3) - Nomenclature

<table>
<thead>
<tr>
<th>Sample Name</th>
<th>Pyrolysis Temp (°C)</th>
<th>Activation Temp (°C)</th>
<th>Activation Time (hrs)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDS XXX</td>
<td>XXX</td>
<td>-</td>
<td>-</td>
<td>CDS pyrolysed at XXX°C</td>
</tr>
<tr>
<td>AC-OPT-OPT-1H</td>
<td>OPT</td>
<td>OPT</td>
<td>T</td>
<td>CDS pyrolysed at OPT°C, and activated at same temp. for T hour</td>
</tr>
<tr>
<td>AC-XXX-OPT-OATm</td>
<td>OPT</td>
<td>XXX</td>
<td>OATm</td>
<td>CDS pyrolysed at OPT, and activated at XXX°C for determined OATm</td>
</tr>
<tr>
<td>IR#-H2SO4-CADS-XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>1H</td>
<td>CADS pyrolysed and activated at XXX, with Impregnation ratio X</td>
</tr>
</tbody>
</table>

**Legend:**
- **CDS:** Crushed Date Seeds
- **PDS:** Pyrolysed Date Seeds
- **AC:** Activated Carbon
- **OPT:** Optimum Pyrolysis Temp
- **OATm:** Optimum Activation Time
- **CADS:** Chemically Activated Date Seeds

**Samples**
- **PDS 700:** CDS pyrolysed at 700°C to make PDS
- **AC-800-800-1H:** CDS pyrolysed at 800°C, and activated at same temp. for 1 hour
- **AC-900-800-1H:** CDS pyrolysed at 800°C (OPT), and activated at 900°C for 1 hour (determined OATm)
- **IR0.5-H2SO4-CADS-700:** CDS impregnated with 0.5:1 $\text{H}_2\text{SO}_4$, then pyrolysed and activated at 700°C
Methods (4)

Characterization

Evaluation of physicochemical properties of experimental samples using standardized equipment and processes

- Thermogravimetric analysis (TGA)
- Scanning electron microscopy (SEM) imaging
- Porosity and surface area determination

Adsorption Testing

CO₂ loading capacity & integral heat of adsorption heat at 1 bar: Micro-reaction calorimeter (μRC)

Results (1)

Thermogravimetric Analysis (TGA)

- TGA provided info on parameters (temperature, heating rate, time) for pyrolysis
- Optimum yield is aided by the large amount of fixed carbon and low ash content.
- High volatile matter content also provides good pore volume for active carbons

<table>
<thead>
<tr>
<th>Moisture Content %</th>
<th>Volatile Matter %</th>
<th>Fixed Carbon %</th>
<th>Ash %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.21</td>
<td>72.85</td>
<td>23.62</td>
<td>1.32</td>
</tr>
</tbody>
</table>

Results (2)

Yield of PDS

Yield of AC

Yield of CADS

Impregnation Ratio
Results (3)

Scanning Electron Microscopy (SEM) Imaging

(a) CDS
(b) PDS 600
(c) PDS 800
(d) AC-800-800-1H
(e) AC-800-900-1H
(f) IR1-H2SO4-CADS-700
(g) IR2-H2SO4-CADS-900
(h) Comm. AC
**Results (4)**

### Porosity and Surface Area Analysis

<table>
<thead>
<tr>
<th>Sample</th>
<th>$S_{\text{BET}}$ (m$^2$/g)</th>
<th>Micropore Area (m$^2$/g)</th>
<th>Micropore Volume (cm$^3$/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDS 600</td>
<td>265.418</td>
<td>268.379</td>
<td>0.102</td>
</tr>
<tr>
<td>PDS 700</td>
<td>440.5</td>
<td>420.809</td>
<td>0.163</td>
</tr>
<tr>
<td>PDS 800</td>
<td>531.332</td>
<td>483.776</td>
<td>0.192</td>
</tr>
<tr>
<td>PDS 900</td>
<td>449.805</td>
<td>416.508</td>
<td>0.17</td>
</tr>
<tr>
<td>AC-800-800-1H</td>
<td>627.145</td>
<td>593.709</td>
<td>0.232</td>
</tr>
<tr>
<td>AC-800-2H</td>
<td>659.698</td>
<td>620.996</td>
<td>0.247</td>
</tr>
<tr>
<td>AC-800-3H</td>
<td>192.649</td>
<td>172.359</td>
<td>0.07</td>
</tr>
<tr>
<td>AC-700-800-1H</td>
<td>750.902</td>
<td>679.314</td>
<td>0.268</td>
</tr>
<tr>
<td>AC-900-800-1H</td>
<td>798.378</td>
<td>712.871</td>
<td>0.277</td>
</tr>
<tr>
<td>Comm. AC</td>
<td>698.722</td>
<td>474.576</td>
<td>0.213</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample</th>
<th>$S_{\text{BET}}$ (m$^2$/g)</th>
<th>Micropore Area (m$^2$/g)</th>
<th>Micropore Volume (cm$^3$/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR0.5-H2SO4-CADS-600</td>
<td>376.232</td>
<td>374.971</td>
<td>0.131</td>
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<tr>
<td>IR0.5-H2SO4-CADS-700</td>
<td>420.653</td>
<td>412.68</td>
<td>0.152</td>
</tr>
<tr>
<td>IR0.5-H2SO4-CADS-800</td>
<td>560.6</td>
<td>520.8</td>
<td>0.193</td>
</tr>
<tr>
<td>IR0.5-H2SO4-CADS-900</td>
<td>566.121</td>
<td>523.837</td>
<td>0.189</td>
</tr>
<tr>
<td>IR1-H2SO4-CADS-600</td>
<td>382.3</td>
<td>372.7</td>
<td>0.143</td>
</tr>
<tr>
<td>IR1-H2SO4-CADS-700</td>
<td>422.9</td>
<td>407.6</td>
<td>0.157</td>
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<tr>
<td>IR1-H2SO4-CADS-800</td>
<td>567.32</td>
<td>552.4</td>
<td>0.199</td>
</tr>
<tr>
<td>IR1-H2SO4-CADS-900</td>
<td>571.55</td>
<td>564.49</td>
<td>0.196</td>
</tr>
<tr>
<td>IR2-H2SO4-CADS-600</td>
<td>311.999</td>
<td>339.668</td>
<td>0.115</td>
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<tr>
<td>IR2-H2SO4-CADS-700</td>
<td>441.300</td>
<td>454.700</td>
<td>0.158</td>
</tr>
<tr>
<td>IR2-H2SO4-CADS-800</td>
<td>572.23</td>
<td>567.95</td>
<td>0.206</td>
</tr>
<tr>
<td>IR2-H2SO4-CADS-900</td>
<td>577.34</td>
<td>568.51</td>
<td>0.202</td>
</tr>
</tbody>
</table>
Results (5)

**CO₂ Sorption**

![CO₂ Sorption Diagrams]

- **Best Performance:**
  - AC-900-800-1H: (3.21 mmol/g, 13.62 kJ/mol)
  - IR1-H2SO4-CADS-700: (1.79 mmol/g, 18.84 kJ/mol)
Conclusions

- Activated carbon was successfully synthesized from date seeds of local date fruits by both physical and chemical activation, and efficiency of the adsorbent for CO$_2$ capture was tested;

- Characterization studies showed that UAE date seeds are good starting materials to produce activated carbons for carbon capture applications;

- Chemically activated samples had reduced loading capacity due to influence of chemical agent;

- Overall performance trend indicated physical synthesis is the best route for sorbent preparation from UAE date seeds.

Acknowledgement

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THANK YOU