Microwave pyrolysis of sewage sludge

Presenting author: Jakub Raček

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Outline:

1. **Introduction**: legislative background, practical applications of pyrolysis;
2. **Materials and Methods**: catalysts, microwave pyrolysis technology, dry solids, heavy metals, surface and pore analysis;
3. **Results and discussion**: pellets, design of mixtures, diagram of temperature over time, photos;
4. **Conclusion**: the most suitable catalysts.
1. Introduction

- Presents a microwave technology that has been selected as the optimal available technology for eco-friendly disposal of sewage sludge, ensures fixation of heavy metals in biochar;
- sewage sludge treatment is based on legislation and common practise;
- two alternative methods of thermal treatment:
  - a) gasification;
  - b) pyrolysis.
- the product of pyrolysis is charcoal (biochar) and pyrolysis oil ...
- it complies with global circular economy: carbon footprint production, heavy metal fixation and water retention.
1. Introduction

- Granulation used: for pretreatment of sludge;
- “full-scale“ tests of microwave sludge pyrolysis performed;
- two types of pyrolysis depolymerization:
  - a) standard: heat is transferred into the material through conventional heat transfer so that all material is heated from the surface;
  - b) microwave: the used of microwave radiation depends (electromagnetic field) on the material itself, it is related to its composition, the content of dielectric components.
2. Materials and Methods

- Previous research has shown that lignocellulosic biomass processes without the aid of a catalyst was limited;
- the role of catalyst in supporting the cracking of hydrocarbons is also considerable in the optimized process;
- adding catalyst for depolymerization: Zeolite catalyst, may work at temperatures up to about 250 °C.
3. Results and discussion

• Some photos from AdMaS Research Centre.
2. Materials and Methods

• The negative pressure was maintained at about 200 hPa below normal atmospheric pressure, this at about 800 hPa;

• the main source of sludge for laboratory tests was the WWTP in Brno Modřice (22-day digestion at 35 °C) where the drying sludge (Nara paddle dryer) is heated to 100 °C with a retention time of about 3 hours;

• samples of sludge subject:
  - dry solids: 91.5 – 91.9 %;
  - loss by ignition: 47.1 – 49.0 %;
  - fraction approx. 1 – 8 mm (bound finer fractions).
2. Materials and Methods

- The sewage sludge was mixed with some types of catalysts and additives:
  - a) zeolite ZSM-5,
  - b) zeolite Lehotka BL 200,
  - c) biochar from previous tests – fraction 0.1 – 0.5 mm,
  - d) hay,
  - e) sawdust - fraction approx. 0.1 – 0.5 mm, soft wood,
  - f) lignin – waste from Swedish paper mills.

- Experience from the previous research: the most suitable input mixture is granulated, 6 mm diameter pellets.
2. Materials and Methods

Diagram 1: Typical course of temperatures in time for lignocellulosic biomass (for 6 mm pellets, divided into 3 steps, in cooperation with Bionic, 2014)
2. Materials and Methods

• Dry matter in the input material was about 90% for all the input samples;
• it consists predominantly of nutrients, organic matter and organic micro-pollutants.

Monitored indicators:
- proportion of organic and mineral substances in input and output material;
- dry solids;
- heavy metals;
- surface and pore analysis.
2. Materials and Methods

- Verification of the heavy metal content in biochar was determined using aqua regia leachate and aqueous extracts;
- used equation:

\[
\text{HMfix} = \text{HMar} - \text{HMw} \quad \text{(ng/g)} \quad \text{Eq.1}
\]

- HMfix ... heavy metals fixed in biochar (ng/g);
- MMar ... heavy metal in aqua regia leachate (ng/g);
- HMw ... heavy metals from aqueous extracts (ng/g).
3. Results and discussion

Table 1 – Description of mixtures and output characteristics

<table>
<thead>
<tr>
<th>Mixture description (catalyst to sludge before pelleting. dose related to dry solids)</th>
<th>Sample designation</th>
<th>Biochar yield (%)</th>
<th>Liquid yield (%)</th>
<th>Gas yield (%)</th>
<th>TOC biochar (%)</th>
<th>Organic matter obtained via thermogravimetry (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No catalyst</td>
<td>K0.0</td>
<td>61.0</td>
<td>9.6</td>
<td>29.4</td>
<td>27.4</td>
<td>22.8</td>
</tr>
<tr>
<td>0.5 % zeolite ZSM-5</td>
<td>Z0.5</td>
<td>61.6</td>
<td>13.9</td>
<td>24.5</td>
<td>23.1</td>
<td>30.1</td>
</tr>
<tr>
<td>1.0 % zeolite ZSM-5</td>
<td>Z1.0</td>
<td>58.9</td>
<td>18.2</td>
<td>22.9</td>
<td>29.3</td>
<td>40.3</td>
</tr>
<tr>
<td>2.0 % zeolite ZSM-5</td>
<td>Z2.0</td>
<td>56.8</td>
<td>15.8</td>
<td>27.4</td>
<td>24.4</td>
<td>39.5</td>
</tr>
<tr>
<td>2.0 % zeolite ZSM-5 + ca 2.0 % hay</td>
<td>Z2.0 G</td>
<td>62.1</td>
<td>19.3</td>
<td>18.6</td>
<td>33.6</td>
<td>34.4</td>
</tr>
<tr>
<td>0.5 % zeolite BL200</td>
<td>L0.5</td>
<td>56.7</td>
<td>20.0</td>
<td>23.4</td>
<td>27.1</td>
<td>35.8</td>
</tr>
<tr>
<td>1.0 % zeolite BL200</td>
<td>L1.0</td>
<td>58.1</td>
<td>13.5</td>
<td>28.4</td>
<td>26.2</td>
<td>35.5</td>
</tr>
<tr>
<td>2.0 % zeolite BL200</td>
<td>L2.0</td>
<td>53.5</td>
<td>25.2</td>
<td>21.3</td>
<td>27.2</td>
<td>27.5</td>
</tr>
<tr>
<td>2.0 % zeol. BL200 + ca 2.0 % hay</td>
<td>L2.0 G</td>
<td>63.4</td>
<td>19.3</td>
<td>17.4</td>
<td>39.4</td>
<td>44.6</td>
</tr>
<tr>
<td>0.5 % biochar 0.1 - 0.5 mm</td>
<td>C0.5</td>
<td>57.0</td>
<td>19.7</td>
<td>23.3</td>
<td>29.4</td>
<td>32.6</td>
</tr>
<tr>
<td>1.0 % biochar 0.1 - 0.5 mm</td>
<td>C1.0</td>
<td>63.7</td>
<td>11.5</td>
<td>24.8</td>
<td>23.1</td>
<td>30.5</td>
</tr>
<tr>
<td>2.0 % biochar 0.1 - 0.5 mm</td>
<td>C2.0</td>
<td>58.9</td>
<td>20.6</td>
<td>20.5</td>
<td>29.6</td>
<td>35</td>
</tr>
<tr>
<td>1.0 % zeolite ZSM-5 + 30 % lignin</td>
<td>Z1.0 LIG30</td>
<td>59.6</td>
<td>21.1</td>
<td>19.3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1.0 % zeolite ZSM-5 + 30 % sawdust</td>
<td>Z1.0 SD30</td>
<td>58.5</td>
<td>16.7</td>
<td>24.8</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
3. Results and discussion

• In most samples, moisture evaporated within 60 – 80 minutes of magnetron power at 83 %, which equals approx. 2.5 kW;
• approximately half of the samples reacted to the same power by such an increase in the temperature in the second phase of the process that the magnetron power had to be limited: First to 65 % and then to 35 %;
• drop in the so-called "heating-rate", - downstream the highlighted points (for Z2.0: 140 and 160 min at 171 °C and 192 °C, respectively).
3. Results and discussion

Diagram 2: Temperature over time – 6 mm pellet processing
3. Results and discussion

• It has been shown that the addition of zeolite ZSM-5 (2.0) achieves the best temperature increases mainly with lignin or lignocellulosic additives;
• heavy metals (HM) were evaluated according to Eq. 1 to determine the quantity of HM in biochar;
• Zn, Cd, Pb, Cu, As and Cr metals were monitored;
• depending on individual metals, fixation of 81% up to almost 100% of HM in biochar was achieved.
4. Conclusion

• A few variants of catalysts and additives (zeolite/sawdust/hay/lignin) have been tested;
• the zeolite ZSM-5 at a concentration of 2.0% seems to be the most suitable additive for heating this particular sludge;
• the other catalysts do not show such heating efficiency after the first step of pyrolysis - evaporation of moisture.
4. Conclusion

• Microwave pyrolysis produced these products:
  - liquid and gaseous components, it is possible to predict their use as a certain ecologically fuel;
  - solid biochar can be used in a wide spectrum of applications such as agriculture, landscape water management, wastewater treatment;
• the results are the basis for future research focusing on optimal catalytic depolymerization of sewage sludge by microwave pyrolysis;
• exactly we are testing lignin or sawdust with sequential sludge (Z1.0 lig30 or Z1.0 SD30).
THANK YOU FOR YOUR ATTENTION

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