Life cycle assessments of materials for fluoride removal from drinking water in East Africa

T. L. Yami*, J. Du, L.R. Brunson, J.F. Chamberlain, E.C. Butler, D.A. Sabatini
University of Oklahoma, Norman, United States
*CEES, 202 W. Boyd St.; Room 334; Norman, OK 73019,
Tel: 405-831-7033 , Fax - 405-325-4217, e-mail - Teshome.Lemma-1@ou.edu

Introduction

- Elevated fluoride concentration affects over 200 million people health worldwide (Amini et al. 2008).
- Production of fluoride adsorbents can cause negative environmental impacts.
- Life Cycle Assessment (LCA) can evaluate potential negative environmental impacts of producing fluoride adsorbents and optimize materials selection.

Goals and scope

Goals
- Determine which of the tested fluoride adsorbents have the lowest environmental impacts.
- Evaluate which life cycle stage for each material causes the greatest negative environmental impacts.

Scope of the LCA

Functional Unit
- The quantity of adsorbent necessary to remove fluoride from 100,000 liters of water with a starting concentration of 10 mg/L to meet the World Health Organization safe drinking-water level of 1.5 mg/L.
- A total of 250 persons (50 households) can use 100,000 L of treated water for three months.
- The quantity of adsorbents required based on the functional unit and Q_{equ} is shown in Table 1. Q_{equ} is the fluoride adsorption capacity at equilibrium fluoride concentration of 1.5 mg/L.

<table>
<thead>
<tr>
<th>Adsorbents</th>
<th>Q_{equ} (mg/g)</th>
<th>Total mass of the adsorbent equal to the functional unit (kg)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activated alumina</td>
<td>0.8</td>
<td>1063</td>
<td>Brunson, unpublished</td>
</tr>
<tr>
<td>Bone char</td>
<td>1.71</td>
<td>496</td>
<td>Brunson &amp; Sabatini, 2009</td>
</tr>
<tr>
<td>Amended wood char</td>
<td>0.13</td>
<td>6538</td>
<td>Brunson and Sabatini, in review</td>
</tr>
<tr>
<td>Treated alum waste</td>
<td>3.4</td>
<td>253</td>
<td>Sujana et al., 2005</td>
</tr>
</tbody>
</table>

Assumptions
- Infrastructure and repeatedly used utilities are common to all processes and thus not included in the analysis.
- Negligible adsorbents were lost during processing and treatment.
- Wood chips were used as both charred material and energy source.
- The allocation factor for treated alum waste was 20%.
- Regeneration of adsorbents was not considered in this initial analysis.

Method
- The environmental impacts of fluoride adsorbents were evaluated using life cycle assessment (LCA).
- Eco-indicator and Tools for Reduction and Assessment of Chemicals and other Environmental Impacts (TRACI) were used in this analysis.

Table 1 Total mass of adsorbents needed to lower the fluoride concentration of 100,000 liters of water from 10 mg/L to 1.5 mg/L

Fig. 1 Process flow diagram

Results

- Aluminum oxide amended wood char had the highest overall negative environmental impact in all impact categories (Fig. 2), consistent with having the lowest adsorption capacity (lower Q_{equ}, Table 1).
- Bone char and treated alum waste had the lowest environmental impact (Fig. 2).
- Raw materials acquisition is the life cycle stage that contributed most to the negative environmental impact of aluminum oxide amended wood char (Fig. 3).
- For activated alumina, transportation by ship had lower impact than aircraft transport for respiratory inorganics and fossil fuels impact categories (Fig. 4).
- For each adsorbent, different dominant processes contributed to damage to impact categories (Fig. 5) (e.g. for activated alumina: transportation, bone char: cattle raising, aluminum oxide amended wood char: wood charring, and treated alum waste: H2SO4 production are the dominant processes).

Fig. 2 Impact comparison using (a) eco – indicator (b) TRACI

Fig. 3 Damage assessments for the adsorbents at each life cycle stage

Fig. 4 Effects of transportation distance and means of transportation of activated alumina on the (a) respiratory inorganics and (b) fossil fuels impact categories

Fig. 5 Processes contributing to each damage category for each adsorbent

Limitations

- Limited data availability (e.g. specific emission data on bone charring and quantity of bone char recovered from bone charring).
- Data from Europe/USA may be unrealistic for Africa (e.g. Transportation).

Conclusions and Recommendations

- Higher fluoride adsorption capacity reduces environmental impacts.
  o Develop more effective adsorbents
  o Regeneration and reuse of spent adsorbents has the potential to minimize impacts to ecosystem quality.
  o Transportation of adsorbents from abroad produced higher impacts.
  o Locally produced high efficiency adsorbents are desirable
  o LCA can further guide development of future sustainable systems.
  o Continue developing data appropriate for developing countries

Acknowledgment
This work was funded by the WaTERCenter, Sun Oil Company Endowed Chair, Ken Hoving Graduate College Fellowship and the National Science Foundation (NSF) (CBET-1066425).

References