Continued evaluation of phosphorus-removal media for use in onsite wastewater treatment systems

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BACKGROUND

Primary production in Otsego Lake, as in most inland water bodies, is limited by phosphorus (Harman et al. 1996); increases in that nutrient will lead to excessive algal growth, reducing water clarity and dissolved oxygen (jeopardizing its cold-water fishery) and reducing the value of the lake as a potable supply. Previous Biological Field Station (BFS) research has implicated near-lake onsite wastewater treatment (“septic”) systems as a meaningful source of phosphorus (Meehan 2004). While phosphorus removal units are commercially available, few are geared for residential use, they are costly, and BFS monitoring suggests that they are short lived (Waterfield 2010). The current DEC-funded work entails the evaluation of various media which may yield cost-effective promise for phosphorus removal from domestic wastewater. Concurrent work involved field monitoring of “demonstration” advanced treatment systems installed around Otsego Lake (Waterfield 2011).

This report updates findings reported in Albright and Waterfield (2010), which focused primarily on the evaluation of iron oxide and aluminum oxide media, and included some preliminary data on Polonite® and “Media X”. Here, evaluations of those latter two media are more fully provided and all media are compared.

METHODS

The primary intention of this work is to evaluate bench-scale modules packed with various media having the capacity to intercept phosphorus from onsite wastewater treatment system effluent. Some media are commercially manufactured, some are naturally occurring and some are waste products from other processes.

Media description

Six different media were evaluated. The first three are developmental aluminum oxide-coated waste aggregate. The first batch tested was in the 0.85-2.00 mm size range, the second was 2.00-4.75 mm, and the third was pretreated with proprietary processes to reduce its pH effects on water. The fourth is a marketed iron oxide bearing media designed for the removal of arsenic from water. It has also been demonstrated to be effective at phosphorus removal. Unlike other iron oxide media, this is not calcite-rich and works by adsorption rather than mineralization. The fifth material, Polonite®, is produced by heat-treating opoka rock, a

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calcium silicate based material marketed by Bioptech™. An overview of the chemistry related to phosphorus removal by aluminum oxides and Polonite® is provided in Gustafsson et al. (2008) and Westholm (2006). The last material evaluated, termed “Media X”, is a byproduct of drinking water treatment processes. It consists mainly of the precipitated hydroxides or carbonates of the coagulant along with other treatment additives such as polymers and materials removed from the raw water (sand, silt, clay, algae, color-forming compounds). In this case the water treatment residuals are composed primarily of alum and a cationic polymer.

**Lab setup**

The body of each module was constructed from standard 300 ml BOD bottles, the bottom having been removed with a glass saw. Size #2 rubber stoppers were bored to accommodate 5 mm OD glass tubing, which was ~8 cm and bent to 90° at its mid point. One end was inserted through the stopper and mesh (a 1 X 1 cm piece of paint strainer) was glued across the stopper to prevent media fines from clogging the tube. The stopper assembly was glued into the BOD bottle opening and ~20 cm of 4 mm ID (6 mm OD) Tygon™ tubing was attached to the exterior end of the glass tubing. The assembled units were secured to ring stands and the Tygon™ tubing was secured to the outside of the BOD bottle with rubber bands. Paper clips were used to create a “goose neck” such that the end of the tubing was ~2 cm below the level of the top of the assembled unit. Figure 1 demonstrates the unit design. Alternatively, some units were modified to represent “unsaturated flow”. These were as above, without the vertical tubing so that the waste flowed vertically downward. All units were situated over plastic tubs which drained into a waste holding vessel.

For each media used, the mass and pore volume of 200 cm³ was determined (Table 1). This amount was added to the modules. The “influent” to the modules was secondarily treated municipal sewage from the Village of Cooperstown which had been augmented, with potassium phosphate, to ~10 mg/l-P to better reflect total phosphorus concentrations in local onsite systems (Waterfield 2009; 2010). (The TP content in the municipal effluent is generally ~3 mg/l-P). The rationale for using influent was that the chemical constituency would likely reflect that by local septic waste. Other negative ions have, in some instances, been shown to compete with phosphorus for binding (Adam et al. 2007). The solution was stored in a large drum, augmented as needed, and constant aeration was applied to mimic conditions in typical treatment systems.
<table>
<thead>
<tr>
<th>Media</th>
<th>Vol. (cm³)</th>
<th>Wt (g)</th>
<th>Bulk Density (g/cm³)</th>
<th>Pore Vol. (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum oxide 0.85-2.00 mm (“fine”)</td>
<td>200</td>
<td>183</td>
<td>0.92</td>
<td>116</td>
</tr>
<tr>
<td>Aluminum oxide 2.00-4.75 mm (“coarse”)</td>
<td>200</td>
<td>207</td>
<td>1.04</td>
<td>115</td>
</tr>
<tr>
<td>Aluminum oxide “treated”</td>
<td>200</td>
<td>240</td>
<td>1.20</td>
<td>120</td>
</tr>
<tr>
<td>Iron oxide</td>
<td>200</td>
<td>125</td>
<td>0.63</td>
<td>143</td>
</tr>
<tr>
<td>Polonite®</td>
<td>200</td>
<td>178</td>
<td>0.89</td>
<td>160</td>
</tr>
<tr>
<td>“Media X”</td>
<td>200</td>
<td>160</td>
<td>0.80</td>
<td>160</td>
</tr>
</tbody>
</table>

Table 1. Weight, density and pore volumes of 200 cm³ of each media tested.

Tygon™ tubing (2 mm ID, 3 mm OD) was used to deliver the waste from the storage drum to each module. At the drum end, the tubes were bundled, covered with a strainer and weighted so that they would reach the bottom of the vessel. The tubes were suspended over each module by inserting them into a pre-drilled plastic Petri dish which was placed over the units. A Technicon™ peristaltic pump was installed in-line; pump tubing of varying diameters allowed for the selection of different flow rates. The pump ran more or less continuously; individual modules were occasionally off line due to tube blockages or pump tube failures. These were of short duration and were not addressed during data processing. Outflow samples were collected 1-2 times per week by placing beakers under the module outlets. Inflow (high-P wastewater) samples were collected concurrently so that removal efficiencies of the modules could be calculated. Total phosphorus was measured on all samples collected. The effect of pH on the samples by media was evaluated in 2009 (Albright and Waterfield 2010).
Lab Analysis

Nutrient analyses used a Lachat QuikChem FIA+ Water Analyzer. Samples were analyzed for total phosphorus using ascorbic acid following persulfate digestion (Liao and Martin 2001).

RESULTS AND DISCUSSION

Phosphorus Removal

The percent phosphorus removed is plotted versus module bed volumes for Polonite® at 3.6 bed volumes/day (bv/day), saturated and unsaturated flow, in Figure 2 and for “Media X” in Figure 3. “Media X” phosphorus removal in saturated conditions at 5.1 bv/day is shown in Figure 4. As with the iron oxide and aluminum oxide materials evaluated in 2009 (Albright and Waterfield 2010), all media performed well (>90% phosphorus removed) during the initial stages of the evaluation. Saturated flow regimes outperformed unsaturated conditions, likely due to better and longer contact between with the media (vs. preferential flow through the unsaturated conditions). The importance of contact time is further suggested in that faster flow rates had somewhat poorer performance (Figure 4 vs. Figure 3). Figures 5 and 6 illustrate the cumulative amounts of phosphorus removed (g) per kg of media for Polonite® and “Media X”, respectively. Complete performance evaluations for iron oxide and aluminum oxide media are provided in Albright and Waterfield (2010).

![3.6 Bed Volumes per Day](image)

Figure 2. Percent phosphorus removal for Polonite® under saturated and unsaturated conditions at 3.6 bed volumes/day.
Figure 3. Percent phosphorus removal for “Media X” under saturated and unsaturated conditions at 3.6 bed volumes/day.

Figure 4. Percent phosphorus removal for “Media X” under saturated conditions at 5.1 bed volumes/day.
Figure 5. Cumulative phosphorus removed, in g/kg media, vs. bed volumes for Polonite®.

Figure 6. Cumulative phosphorus removed, in g/kg media, vs. bed volumes for “Media X”.
CONCLUSIONS

All media evaluated to date had initial phosphorus removal rates over 95%. The sustained ability for long term removal, however, varied considerably among media type. In general, slower flow rates through a given media were associated with higher phosphorus retention rates, though those differences were not substantial at rates less than 5.1 bed volumes per day. When compared, saturated flow regimes had higher retention rates than unsaturated flows.

Table 2 summarizes the amount of phosphorus retained per kg of each media to the point where removal efficiencies remained consistently above 80% and above 50% (these were considered benchmarks of success in the evaluation of promising media). The latter criterion was not reached for some media because some modules were ended due to hydraulic failure before efficiencies dropped to 50%. The phosphorus retention by “Media X” was greater than that documented in the literature for other cost effective media (Gustafsson et al. 2008; Westholm 2006).

<table>
<thead>
<tr>
<th></th>
<th>&gt;80%</th>
<th>&gt;50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron Oxide (5.1 bv/day)</td>
<td>11.2</td>
<td>NA</td>
</tr>
<tr>
<td>Aluminum Oxide fine (5.1 bv/day)</td>
<td>8.0</td>
<td>NA</td>
</tr>
<tr>
<td>Aluminum Oxide coarse (5.1 bv/day)</td>
<td>6.7</td>
<td>NA</td>
</tr>
<tr>
<td>Aluminum Oxide treated (5.1 bv/day)</td>
<td>3.4</td>
<td>5.1</td>
</tr>
<tr>
<td>Polonite (3.6 bv/day)</td>
<td>6.7</td>
<td>10.3</td>
</tr>
<tr>
<td>&quot;Media X&quot; (3.6 bv/day)</td>
<td>13.6</td>
<td>16.5</td>
</tr>
</tbody>
</table>

Table 2. Amount of phosphorus (g) retained per kg of media to the point where removal efficiencies dropped consistently below 80% and below 50%.

Another criterion for a successful phosphorus removal candidate was related to pH influences on the treated wastewater; other studies have indicated that some metal oxide media have the potential for elevating pH values substantially (Baker et al. 1998). While this issue does not preclude these media from being pursued, it would necessitate some form of final treatment to bring the effluent into compliance (pH = 6.5-8.5; O’Connor 2010)). Previous work by Albright and Waterfield (2010) evaluated pH of the media effluent over several hundred bed volumes. The aluminum oxide material elevated pH to ~12 initially, and it was >pH 10 for about 300 bed volumes. The “pH treated” aluminum oxide was initially about pH 9.5, and it soon dropped below 9.0, though the phosphorus removal efficiency was lower than its non-treated counterpart (see Table 2). Polonite® also elevated the pH, initially to ~11, and above pH 10 for the first few hundred bed volumes. The iron oxide material initially produced effluent >pH 8.5, but within 100 bed volumes it was <pH 8.5. “Media X” had a pH of 7.5 and 8.0 throughout the period of testing.
SUMMARY

The criteria considered for the most promising media include phosphorus-removal efficiency and longevity, pH influences on the wastewater, and cost of the material. (Costs are not explicitly reviewed here, though they vary considerably. The metal oxides evaluated here are reportedly in the range of ~$2-$20/lb ($4-$40/kg). Polonite is less expensive, but is shipped from overseas. “Media X”, being a waste product from other applications, is considerably less expensive and can be acquired in the northeast USA). “Media X”, having demonstrated superior phosphorus removal potential, no undesirable pH influences on the wastewater, and being the least expensive, clearly holds the most promise for use associated with onsite treatment systems.

Based on a review of local conditions, phosphorus generation per capita is approximately 0.58 kg/person/year (160 l/person/day*365*10 mg/l); this is close to that estimated by Dillon and Rigler (1975) of 0.8 kg/person/year prior to the high phosphate detergent ban. If the phosphorus removal efficiency in the field approximates that demonstrated in the lab, then 43 kg of “Media X” should address the phosphorus generated by each resident for one year. Based on the density of “Media X”, one cubic yard (0.75 cubic meters) weighs 610 kg. The amount of media should therefore effectively remove phosphorus at the 80%+ rate for the equivalent of 14 resident-years (for example, a full time residence of 4 people for three and a half years). Given the pore volume of “Media X” (80% of actual volume, see Table 1), one cubic yard would have a pore volume of 600 l (~150 gal). Wastewater generation is typically about 40 gal/day, so the volume going through the media module would typically be less than 1 bed volume/day, indicating more than adequate contact time for effective treatment.

REFERENCES


