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Pilot-scale application of shotblast dust for phosphorus removal

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Abstract

Phosphorus contamination is a global issue, and cost-effective remediation is sought for removing phosphorus from water. We applied a novel use of waste material called shotblast dust in a pilot-scale reactor to remove phosphorus from water. Results indicate that shotblast dust was effective in treating phosphorus-laden water with 132 kg of the material treating 568 liters of 220 µg/L total phosphorus (T-P) water on a daily basis, achieving approximately 60% removal of T-P in 7 days.

Keywords

Shotblast dust; Phosphorus; Waste material; Iron; Remediation

Introduction

Phosphorus pollution arises from various sources including runoff that contains human waste as well as fertilizers from farms, livestock, and industry (Smith et al., 2015; Jobgen et al., 2004; Ballantine, et al., 2010; Huang et al., 2017). Excessive phosphorus in water causes eutrophication, which has many undesirable traits including excessive growth of algae and development of hypoxia in aquatic ecosystems (Schindler, 2016; Daniel et al., 1998; Conley

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et al., 2009; Havens, 2003). The formation of algal blooms may also be associated with release of toxins into the environment, causing loss of biodiversity, fish kills and deterioration of water quality (Paerl et al., 2001; Havens, 2008; Pitcher et al., 2006). Eutrophication has been found in many aquatic ecosystems in Florida, such as Kissimmee River, Lake Okeechobee and the Everglades (The weather channel, 2016; Circle of blue, 2016).

Filtration materials such as sand and iron could act as inexpensive adsorbents of water borne contaminants. In previous studies, iron oxides were useful in eliminating heavy metals from aqueous solutions (Yoon et al., 2014; Mittal et al., 2017; Boujelben et al., 2008). Current technology in treating phosphorus laden water (such as stormwater treatment areas or STAs in South Florida) is costly and an alternative technology is needed. In this study, shotblast dust was applied as a novel, potentially cost-effective adsorbent for removing phosphorus from water. This study investigated the efficacy of shotblast dust to treat phosphorus-laden water in a pilot-scale reactor and evaluated its cost-effectiveness in remediation of aqueous phosphorus in field systems.

Materials and methods

Design of a pilot-scale reactor for the treatment of phosphorus-laden water

The waste material shotblast dust, of which US Foundry produces approximately 2.5 tons per day during post-processing of steel products after molding, is 83.3% silica, 14.5% iron, and 2.2% aluminum. The surface area of the shotblast dust used in these trials was approximately $3.30 \pm 0.09 \text{ m}^2/\text{g}$, and more than 88% (by weight) of shotblast dust particle sizes ranged from 1.4 to $1.0 \text{ }\mu\text{m}$. A reactor or contactor (Fig.1) was built from a plastic barrel (Height: 68.58 cm, Diameter: 68.58 cm) with a PVC pipe installed at the bottom. The PVC pipe (Height: 40 cm, Diameter: 1.3 cm) was perforated with 144 holes and surrounded by a filter made from a $1 \text{ }\mu\text{m}$ wound polypropylene string. The reactor was filled with 132 kg of shotblast dust, packed into four sack bags. Water was pumped into the reactor through a diffuser installed inside the reactor. A schematic of the overall treatment system is illustrated in Fig. 2.

Experimental procedures

A plastic tote (Height: 90.2 cm, Width: 91.4 cm, and Length: 109.2 cm) was filled with filtered deionized water via an Evoqua DI cartridge (total 568 liters), and 124.93 mL of a phosphorous stock solution (1,000 mg/L total phosphorous (T-P) in 1% HNO_3 , 0 salinity; SCP Science, Quebec, Canada) was added to make 220 $\mu\text{g/L}$ T-P. The 220 $\mu\text{g/L}$ T-P solution was fed into the reactor through a diffuser. After the reactor was set up, an inflow sample was taken from the tote. The outflow rate from the reactor was approximately 0.8–2.5 mL/min. The reactor was operated over a 5–6-hour period to treat 568 liters of water. The shotblast bags inside the reactor were not changed during the experiments. The inflow and outflow samples for analysis were taken using an approximately 100 mL polypropylene bottle that was acid washed, and all samples were kept at a 4 °C. After their collection, all samples from the tote and the reactor were sent to ALS laboratory in Jacksonville, FL to measure T-P concentrations while orthophosphates were measured at the EPA Gulf Ecology

Dision lab. The procedures of sampling, packing, and shipping followed an approved analytical EPA method (365.1).

Results and Discussion

Figure 3A shows the removal kinetics of 220 µg/L T-P over one week. Although there appears to have been a significant decrease (98% removal) in the first day, approximately 50% of T-P remained the effluent after 7 days. Noticeably, steady increases in effluent T-P concentrations were observed as time passed, likely because of gradual saturation of sorption sites and desorption of T-P after an initial adsorption on the surface of shotblast dust. The cumulative amounts of T-P from days 1 to 7 are shown in Figure 3B. Notably, despite a significant passage of T-P mass above 476 mg with a total water volume of 3,975 liters by day 7, the initial removal rate of 98% decreased to approximately 60% in 7 days. Although the removal capacity appears to decrease as more phosphorus-laden water is treated, treatment efficacy remained relatively high. The pH values of the inflow and the outflow were relatively constant at approximately 6.2–6.3 during the pilot-scale operation. Given that pH values were below the point of zero charge of iron oxides, and the primary contents of the shotblast dust are iron and silica, more than half of the total phosphorus may have undergone strong adsorption with possible complexation due to iron oxides present in the shotblast dust. Because the primary mechanisms of P removal occur through adsorption and chemical precipitation, the removal kinetics of orthophosphate concentrations was also assessed. As shown in Figure 3C, significant removal of orthophosphate was observed for at least 3 days of treatment, whereas increases in concentrations occurred from days 4 to 7.

Conclusions

The novelty of this study lies in applying shotblast dust, a waste byproduct which is typically landfilled, in a pilot-scale reactor designed for phosphorus removal. After high initial removal of T-P and orthophosphate in 1 day, a relatively high removal rate persisted over 7 days, despite no replacement of the shotblast dust. Further optimization of T-P removal could be achieved by adjusting ratios among the shotblast dust, water volume, T-P concentrations and flow rate. Recovery could be achieved by adjusting the pH (>12 for T-P recovery) to elute the adsorbed P. The benefits of applying this technology include cost-effectiveness, use of simple equipment, potential land application of the used shotblast dust (recycling the spent material into land), and no electrical power required in field applications of this technology (gravity-fed flow). This study demonstrated an environmentally friendly approach to treating phosphorus-containing water in a pilot-scale reactor. Longer term studies should be explored.

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References

- Ballantine DJ, & Tanner CC (2010). Substrate and filter materials to enhance phosphorus removal in constructed wetlands treating diffuse farm runoff: a review. *New Zealand Journal of Agricultural Research*, 53, 1.
- Boujelben N, Bouzid J, Elouear Z, Feki M, Jamoussi F, & Montiel A (2008). Phosphorus removal from aqueous solution using iron coated natural and engineered sorbents. *Journal of Hazardous Materials*, 151, 1. [PubMed: 17997034]
- Circle of blue. (2016). Toxic Algae Flourish as Everglades Solution Eludes Florida. Available at: <http://www.circleofblue.org/2016/north-america/toxic-algae-flourish-everglades-solution-eludes-florida>
- Conley DJ, Paerl HW, Howarth RW, Boesch DF, Seitzinger SP, Karl E, & Gene E (2009). Controlling eutrophication: nitrogen and phosphorus. *Science*, 123
- Daniel TC, Sharpley AN, & Lemunyon JL (1998). Agricultural phosphorus and eutrophication: A symposium overview. *Journal of Environmental Quality*, 27, 2.
- Everglades Foundation. (2016). The Georgy Barely Water Prize. Available at: <http://www.barleyprize.com>
- Havens KE (2003). Phosphorus–algal bloom relationships in large lakes of south Florida: implications for establishing nutrient criteria. *Lake and Reservoir Management*, 19, 3.
- Havens KE (2008). Cyanobacteria blooms: effects on aquatic ecosystems. Cyanobacterial harmful algal blooms: state of the science and research needs. *Adv Exp Med Biol*. 2008;619:733–47. doi: 10.1007/978-0-387-75865-7_33. [PubMed: 18461790]
- Huang J, Xu CC, Ridoutt BG, Wang XC, & Ren PA (2017). Nitrogen and phosphorus losses and eutrophication potential associated with fertilizer application to cropland in China. *Journal of Cleaner Production*, 159.
- Mittal VA, Ellis A, Ye A, Edwards PJ, & Singh H (2017). The adsorption of orthophosphate onto casein-iron precipitates. *Food Chemistry*, 239.
- Jöbgen A, Palm A, & Melkonian M (2004). Phosphorus removal from eutrophic lakes using periphyton on submerged artificial substrata. *Hydrobiologia*, 528, 1.
- Paerl HW, Fulton RS, Moisaner PH, & Dyble J (2001). Harmful freshwater algal blooms, with an emphasis on cyanobacteria. *The Scientific World Journal*, 1.
- Pitcher GC, & Weeks SJ (2006). 7 The variability and potential for prediction of harmful algal blooms in the southern Benguela ecosystem. *Large Marine Ecosystems*, 14.
- Prochaska CA, & Zouboulis AI (2006). Removal of phosphates by pilot vertical-flow constructed wetlands using a mixture of sand and dolomite as substrate. *Ecological Engineering*, 26, 3.
- Schindler D Reducing Phosphorus to Curb Lake Eutrophication is a Success. *Environ. Sci. Technol*, 2016, 50 (17), pp 8923–8929 DOI: 10.1021/acs.est.6b02204 [PubMed: 27494041]
- Smith DR, King KW, Johnson L, Francesconi W, Richards P, Baker D, & Sharpley AN (2015). Surface runoff and tile drainage transport of phosphorus in the midwestern United States. *J Environ Qual*. 2015 3;44(2):495–502. doi: 10.2134/jeq2014.04.0176. [PubMed: 26023968]
- W., Carpenter SR, Chapra SC, Hecky RE, & Orihel DM (2016). Reducing phosphorus to curb Lake Eutr tile drainage transport of phosphorus in the midwestern United States. *Journal of Environmental Quality*, 44, 2.
- The Weather Channel. (2016). 10 Things to Know about Florida’s Harmful Algae Blooms. Available at: <https://weather.com/science/nature/news/florida-algae-crisis>
- Yoon SY, Lee CG, Park JA, Kim JH, Kim SB, Lee SH, & Choi JW (2014). Kinetic, equilibrium and thermodynamic studies for phosphate adsorption to magnetic iron oxide nanoparticles. *Chemical engineering journal*, 236.

Fig. 1. Configuration of (A) the reactor, (B) the diffuser, (C) the wound-string filter, and (D) the reactor with the diffuser and the wound-string filter at the bottom

Fig. 2.
Configuration of the phosphorus-removal system (A) and the experimental setup of the reactor, the tote, as well as the DI cartridge (B)

A

B

C

Fig. 3. Removal kinetics of T-P (inflow: 220 $\mu\text{g/L}$) (A), accumulated T-P and its removal rate over time (B), and orthophosphates (C)