Phosphorus Removal in Urban Runoff Using Adsorptive Filtration Media

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ABSTRACT

Elevated concentrations of particulate, dissolved, and total phosphorus (TP) have been increasingly documented in results from stormwater monitoring projects across the nation. Conventional stormwater treatment processes, such as sedimentation, hydrodynamic separation and inert media filtration, are able to remove a large fraction of particulate matter (especially particles larger than 25 µm) and particulate bound pollutants. However, they can not be relied upon to consistently remove more than 40% of total phosphorus. With the implementation of more stringent stormwater regulations calling for higher levels of phosphorus removal, advanced technologies with higher removal efficiencies are being investigated. A cost-effective, light weight, adsorptive filtration media, EMP, was developed to target the removal of total phosphorus. EMP offers both good adsorption capacity of dissolved phosphorus and retention capacity of particulate phosphorus. Its characteristics and performance were compared with other widely deployed stormwater filtration media such as zeolite, perlite, and granular activated carbon (GAC). Media performance was primarily evaluated using bench-scale testing to determine both dissolved phosphorus adsorption isotherms and adsorption breakthrough. The breakthrough testing utilized horizontal flow columns and tap water spiked by dissolved phosphorus at a pH range commonly found in typical stormwater runoff. Concentrations were based on typical values reported from the nationwide stormwater runoff database. Different specific flow rates were tested to create residence times within the media from a few seconds to a few minutes. Media performance was evaluated by the concentration and mass reduction of total phosphorus. The bench-scale results convincingly illustrate the effectiveness of the newly developed EMP media. Bench-scale results also pave the way for further pilot scale testing and regulatory approvals so the media can be deployed to remove phosphorus in urban runoff and improve the health of receiving waters. Pilot scale field testing is scheduled in the spring and winter of 2009.

Introduction

Eutrophication, which causes deterioration of water quality, typically results from excessive input of dissolved and particulate nutrients. In fresh water the limiting nutrient is often phosphorus (P) and elevated P concentrations have been identified in many types of non-point urban stormwater runoff discharges (USEPA, 1993). It remains a high priority and daunting challenge for the stakeholders of stormwater treatment to effectively control phosphorus loading in order to reduce eutrophication and improve water quality. Many past studies of Best Management Practices (BMPs) in the stormwater runoff showed it is difficult to consistently achieve total phosphorous (TP) removal rates in excess of 40%. However, some regulatory agencies are seeking higher TP removal rates from 50 to 65%, or they are establishing Total Daily Maximum Loads to reduce nutrient loading to predeveloped conditions.

In stormwater runoff, phosphorus is either particulate or dissolved. Particulate forms can be as part of organic structures or mineral precipitates. Traditional stormwater treatment processes, including sedimentation, hydrodynamic separation and inert media filtration, are able to remove a large fraction of these particles (especially particles larger than 25 µm) and hence the associated pollutants, such as phosphorus. These traditional processes do not remove the soluble phosphorus and allow it to pass through to the receiving water body. In addition, bound phosphorus can be solubilized between storms by organic decomposition or redox reactions. Removal rates of total phosphorous are highly variable and are generally lower than required to prevent eutrophication and keep receiving waters healthy. The Clean Water Act requires the development of total maximum daily loads for pollutants like phosphorus which are causing impairments of waters in the United States. Related regulations include Maine's new stormwater standards, implemented in 2006, which ultimately require treatment practices to target both particulate and dissolved phosphorus (Maine Stormwater Best Management Practices Manual, 2006).

The objective of this study was to evaluate the capability of a new adsorptive filtration media, EMP, to remove total phosphorus in stormwater through the synergistic effects of precipitation, adsorption and filtration. EMP was compared with other widely deployed media such as perlite, zeolite and Granular Activated Carbon (GAC) with regard to the dissolved phosphorus removal performance using isotherm testing and flow through experiments.

Methodology

Types of Media Evaluated

Perlite is a naturally occurring volcanic product with good solids removal characteristics. Lightweight, chemically inert, coarse, and granular, it is an effective physical filtration media. Zeolite is a family of natural and synthetic aluminosilicate minerals with soluble metals removal characteristics. GAC is a highly porous adsorbent material, produced by heating organic matter, such as coal, wood and coconut shell in the absence of air, which is then crushed into granules. Targeting both particulate and dissolved phosphorus removal, EMP is a newly developed light weight engineered granular media with active coatings.

Phosphorus Adsorption Isotherms

Phosphorus adsorption isotherms are measured by adding a known amount of media to an aqueous solution spiked with phosphorus salt and analyzing the resulting concentration of solute after a predetermined contact time. Phosphorus concentrations were measured using a colorimeter utilizing ascorbic acid method described by 4500-P in Standard Methods (2005). Phosphorus removal performance of media is shown as maximum phosphorus adsorption capacity in milligrams per gram. Some of the test parameters such as temperature and contact time were held constant. The other test parameters including phosphorus initial concentration, adsorbent solution ratio and solution pH, were variables. The ranges of these variables were selected on the basis of typical values reported from nationwide stormwater runoff database (BMPDB, 2009).

Phosphorus Adsorption Breakthrough

The phosphorus adsorption breakthrough test apparatus is depicted schematically in Figure 1. This testing apparatus is composed of three horizontal flow columns (HFCs) in conjunction with two reservoirs with motorized mixers, a constant head/flow splitter, and a peristaltic pump with associated plumbing. HFCs are the key components of the apparatus because they house the tested filtration media. The HFCs are sized and oriented to replicate a Stormwater Management StormFilter® (StormFilter) cartridge at 1/24th scale. The HFC hydraulically simulates StormFilter cartridge in flow path, velocity and contact time. Influent is continuously fed into the constant head/flow splitter to maintain a constant driving head. The total flow into the constant head apparatus is regulated at a rate to sustain the target flow through each HFC and the overflow is re-circulated back into the influent reservoir. The influent tank is continuously mixed with the mechanical mixer to maintain homogeneity. Flow rates into the HFCs are controlled with graduated ball valves placed downstream of each HFC.

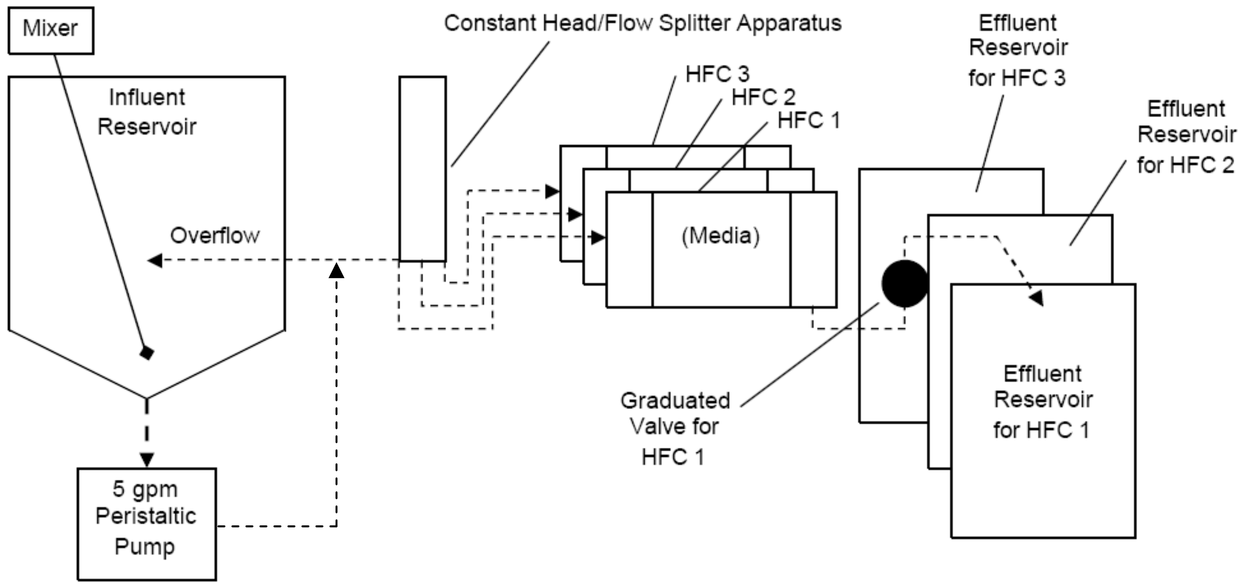

Figure 1. Illustration of the testing apparatus for breakthrough experiment. Dashed lines represent flow. Graduated valves and effluent flow vectors for horizontal flow columns (HFC) of 2&3 have been left out for clarity.

Results and Discussion

Bulk densities of perlite, zeolite, GAC and EMP are shown in Figure 2. Perlite is the lightest media with bulk density generally lower than 10 lbs/ft^3. As the heaviest media, Zeolite has a bulk density of about 45 lbs/ft^3. Lighter than GAC, EMP has a bulk density of about 20 lbs/ft^3. Lighter media is favored because it facilitates easier shipping, handling and maintenance in real world applications.

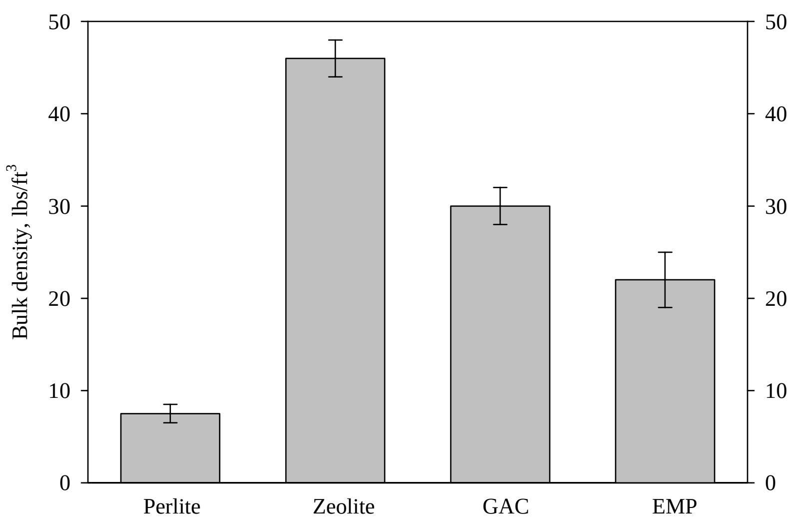

Figure 2. Comparison of media bulk densities.

The media maximum dissolved phosphorus adsorption capacities were compared and are shown in Figure 3. The maximum dissolved phosphorus adsorption capacities ware calculated based on the measurements of media adsorption isotherms. As an inert media, perlite showed negligible phosphorus adsorption capacity. Zeolite and GAC showed improved phosphorus adsorption. The EMP media showed excellent adsorption capacity of nearly 8 mg/g, which is about 5 times the capacity of GAC.

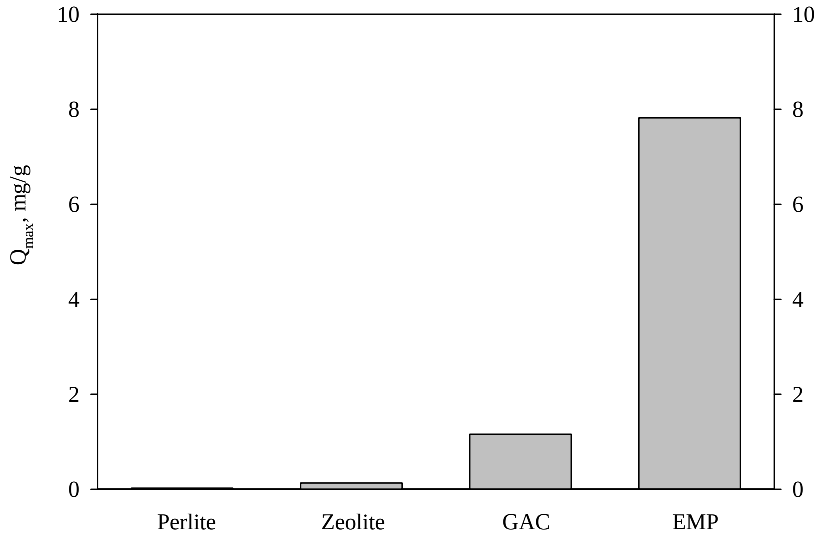

Figure 3. Comparison of media maximum phosphate adsorption capacities by isotherms.

To further evaluate the media, adsorption flow-through testing was carried out on zeolite, GAC and EMP under identical experimental conditions. Because perlite is inert (Lenhart, 2008), it was excluded from this test. Media granules of zeolite, GAC and EMP were loaded into three HFCs respectively. Dissolved phosphorus influent was simultaneously fed through the HFCs at the same flow rate. The influent and three effluents were sampled at a pre-determined time interval and dissolved phosphorus concentrations were measured. The instantaneous phosphorus removals were calculated and plotted against the number of treated bed volumes as shown in Figure 4. This side by side comparison confirmed that EMP provides much higher removals for longer periods of time. EMP treated 2,000 bed volumes of stormwater while GAC and zeolite were exhausted at 1,000 and 10 bed volumes respectfully. For the first 1,000 bed volumes treated, dissolved phosphorus removal rates were 50% and 30% for EMP and GAC respectfully.

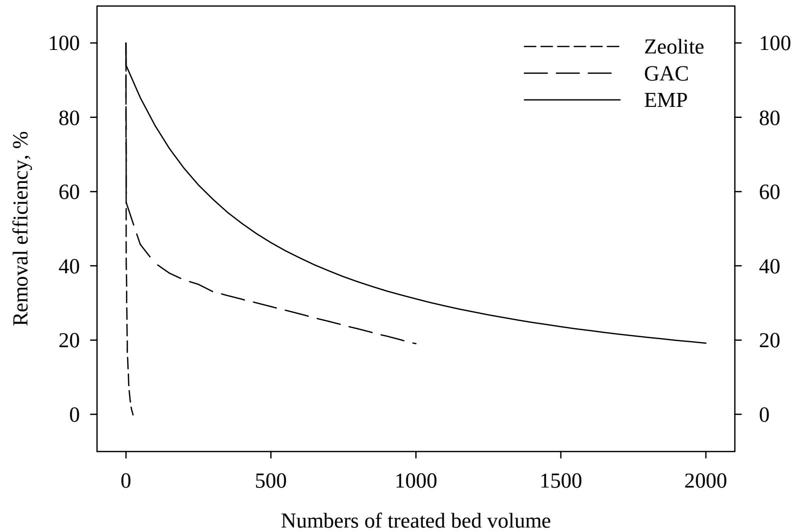

Figure 4. Phosphate adsorption breakthroughs for GAC, Zeolite and EMP media

Conclusions

Although the environmental effect of excessive phosphorus has been well documented and various treatment technologies have been explored in the stormwater treatment industry, there are few established adsorptive filtration media that can satisfy the removal requirements for total phosphorus, especially the dissolved portion. The newly developed EMP media provides significant potential to meet newer, more stringent standards for TP removal. This media is lightweight (<25 lbs/ft^3), inexpensive, and made from non-toxic materials and processes. In bench testing, it offers an average 50% removal of dissolved phosphorus for the first 1,000 treated bed volumes and can last for at least 2,000 treated bed volumes for significant removal. By comparison, the runner up, GAC, can only last about 1,000 bed volumes with an average 30% removal. Field testing is under way to determine the effectiveness of EMP media for total phosphorus treatment in real world applications.

References

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