STORMWATER FILTRATION MEDIA TESTING FOR METALS REMOVAL AND TOXICITY REDUCTION

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ABSTRACT

The Port of Seattle tested four filtration media in controlled laboratory experiments to determine their effectiveness for concurrent metals removal and toxicity abatement in synthetic stormwater. Media tested included commercially available leaf compost (CSF®) media, a zeolite/perlite mix, and a polyamine sponge, as well as the recently developed citric acid modified soybean hull media. Toxicity was assessed using acute *Ceriodaphnia dubia* (48 hr) bioassays.

The CSF® media removed up to 75% of the zinc and reduced toxicity significantly for influent concentrations of up to about 300 ppb zinc. Variations of the CSF® media ("extra fine" and reduced flow rates) improved zinc removal modestly compared to the standard version. The soybean hull material removed 80% to 99% of the zinc over all influent concentrations though it reduced pH to toxic levels. After pH adjustment, the effluent from the soybean material was non-toxic over all concentrations tested (survival was 100% in pH-adjusted effluent samples). Augmenting the soybean material with leaf compost media or activated carbon effectively buffered effluent pH to circum-neutral ranges. Other media tested removed modest amounts of zinc and were capable of sufficiently reducing toxicity only in the lowest concentrations tested, while some media appeared to generate toxicity.

INTRODUCTION

This paper presents the results of a best management practice (BMP) screening study designed to test the effectiveness of filtration media to reduce metals and potential toxicity of stormwater runoff. This work is a follow up to needs identified by NPDES stormwater sampling, whole effluent toxicity (WET) testing and source tracing conducted by the Port of Seattle (the Port) at Seattle-Tacoma International Airport (Port of Seattle 2000, Tobiason et al, 2000). Those studies indicated that stormwater runoff toxicity was associated with zinc from building materials used in certain drainage areas at the airport. Results of the screening study described here will be used to select media for onsite testing as a stormwater treatment BMP at the airport. This future testing may include long-term performance monitoring to determine filtration media stability, lifecycle capabilities and maintenance intervals.

Though there is considerable volume of literature that evaluates metals and other constituent removal by conventional stormwater BMPs, there are few if any studies that have addressed toxicity as well (ASCE 1999, CWP 2000). Most, if not all stormwater guidelines for BMP performance are based solely on their constituent removal performance on a percentage basis (the difference between influent and effluent on a concentration or load basis). Though this type of metric may be appropriate for some constituents, it may be insufficient to judge performance in reducing potential aquatic toxicity of other constituents such as metals.

Others have recently tested a wide variety of organic and other media for wastewater and stormwater treatment, including agricultural waste products such as peanut shells, corn cobs and even kudzu. Most of this work focused on specific adsorption capacities for metals (notably zinc and copper), yet did not examine concurrent toxicity reduction. Several USDA researchers used bench-scale column tests to determine the sorption capacities of the many agricultural waste products for a wide variety of heavy metals. They found that acid-extracted soybean hulls (which were tested and reported in this paper) performed the best and were comparable to commercial grade ion exchange resins (Marshall et al. 1999, 2000; Wartelle and Marshall 2000).

Because the material is a readily available waste product and the acid modification process is relatively simple, the soybean hulls promise to be a cost effective alternative to ion exchange resins for industrial wastewater. What remains to be determined is if the SBH material would work for stormwater applications, providing desirable performance and physical stability over time and the highly variable flowrates and constituent concentrations associated with stormwater runoff. The leaf compost material tested was developed and patented 10 years ago and has been used and tested in a variety of configurations throughout the country as a stormwater treatment BMP (Stormwater Management 1999). This CSF® media is specially composted from pure deciduous leaf feedstock from the City of Portland, Oregon. Performance measurements have focused on removal of target constituents (metals, nutrients, petroleum and sediments).

METHODOLOGY

Photograph 1. Overall test set-up

Testing was conducted at Parametrix using the set-up shown in Photograph 1. The filter media tested included both those that are commercially available such as a deciduous leaf compost (CSF®), Zeolite/ Perlite (ZP), and an inorganic polyamine "sponge", as well as newer experimental media such as Soy Bean Hulls (SBH). Except for the SBH, all media were tested in standard Stormfilter™ cartridge units, which contained a 0.07-m^3 (2.4 ft^3) volume of media. These circular cartridges were fitted in a hydraulic test cell (gray box on left in Photograph 1).

Photograph 2. Horizontal flow (wedge) column.

Because it was available only in smaller quantities, the experimental soybean hull (SBH) medium was tested in a 3000-cm^3 wedge-shaped acrylic horizontal flow column, which mimics about a 4% slice of a Stormfilter™® cartridge volume (Photograph 2). Testing consisted of passing 360L (95 gal) batches of simulated stormwater through the filters at flows up to the recommended maximum of 1-liter/sec (15gpm).

To test the effect of varying influent flow rates, the standard CSF® medium was also tested at one-half the design flow rate of 0.5 l/sec (7.5gpm). Simulated stormwater consisted of synthetic laboratory water (i.e., standardized water used in toxicity testing) spiked at the three different target zinc concentrations. Each target concentration was mixed in two dedicated 210L (55 gal) food-grade polyethylene drums that were drained simultaneously. Each round of testing ran four batches of test water through the filters, beginning with a control (zero zinc), then progressing to the low, mid and high zinc ranges respectively. Prior to testing, each medium was first flushed with at least six volumes of tap water, and then flushed once with de-ionized (DI) water. Furthermore, the filters were flushed with one drum of DI water between batches of test water as well as 60 L (15 gal) of each target zinc concentration. Tests of the SBH medium in the horizontal flow (wedge) column were conducted using the same zinc concentration ranges for the full-scale filter tests, but used scaled flow rates.

Continuous flow-composite samples were collected from the effluent for each batch using a flow-splitter device that delivered approximately 3% of the effluent flow to an 18 L polyethylene cubitainer. Continuous flow composite effluent samples were evaluated for total and dissolved zinc, pH, hardness, dissolved organic carbon (DOC), and acute toxicity with *Ceriodaphnia dubia* (waterflea), using standard test protocols (WDOE 1998a, 1998b; USEPA 1993). *C. dubia* was used since it is one of the most sensitive to metals' toxicity and is routinely the organism of choice for most bioassay laboratories.

Quality controls for the study included filtration controls and up to three replicate tests at each of the target concentrations. The filtration controls consisted of passing unspiked synthetic laboratory water through each of the filter media under the same test conditions. Both pre- and post-filter control samples were subjected to the same chemical and biological testing described above. Grab samples from each test batch were also analyzed for chemical constituents to verify influent concentrations. Staff used clean techniques during all testing and sampling to minimize metals contamination. All of the test apparatus material was plastic and was acid washed (10% reagent grade nitric acid), then rinsed with deionized (DI) water prior to collecting samples.

RESULTS AND DISCUSSION

Testing of the different media occurred in phases as results were reviewed and the testing changed accordingly. These changes included eliminating media that proved unfavorable early in the study or making modifications to the filter media as described below. For example, because the post-filter controls for the "sponge" exhibited zero daphnid survival (most likely associated with the chemical composition of the medium), further testing of the sponge was ceased. In addition, since initial results for the SBH medium showed a large pH (and hardness) reduction, pH was adjusted in the effluent samples using 0.5 M sodium hydroxide prior to toxicity testing. Furthermore, in-situ pH buffering was also tested by augmenting the SBH media with activated carbon and standard CSF® media. In these tests, about 50% of the wedge test cell volume was filled with buffering media while the remainder was the SBH.

Figures 1 to 3 summarize the results of media testing for each of the three target zinc concentrations. To aid interpretation, the percent zinc removal and the percent daphnid survival are presented on the same figure. Overall, the CSF® and SBH media provided the most promising results. Compared to the CSF® and SBH, results for the zeolite/perlite and sponge media were poor, therefore, further testing of these two was ceased.

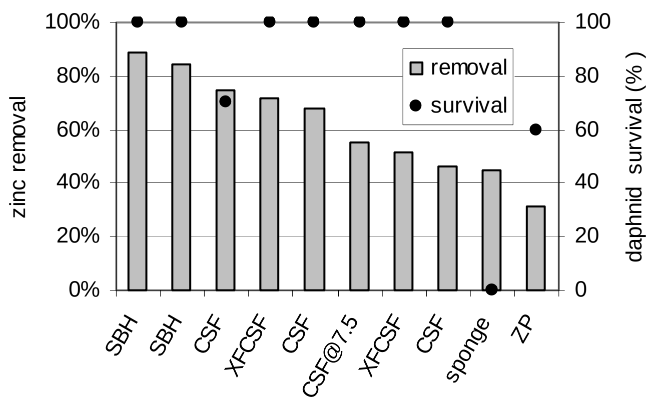

Figure 1 Media Performance at Low Range (100-200 ppb zinc)

Results for the initial round of CSF® tested at one-half the design flow rate were comparable to the standard flow rate, therefore only one round of the low flow rate testing was conducted. Two rounds of testing the XFCSF showed only modest improvements in zinc removal compared with results for the standard CSF®. The SBH effluent zinc concentrations remained consistently low throughout all ranges tested. During 9 of 10 tests over a wide range of influent concentrations, zinc concentrations in the SBH effluent ranged from 13 µg/l to 29 µg/l, averaging 20 µg/l. The highest zinc in SBH effluent was 48 µg/l resulting from the 4.4 mg/l influent, representing 99% removal. Effluent zinc concentrations for the other media generally increased with increasing influent concentrations. Therefore, overall zinc removal was inconsistent and decreased with increasing influent concentration for media other than the SBH. Except for the sponge media, daphnid survival correlated well with effluent zinc concentrations. Inferred LC50s approximated expected LC50s of about 150 µg/l zinc. In general, the organic media added between 3 to 35 ppm DOC, while the mineral medium (zeolite/perlite) added less than 0.5 ppm DOC. The sponge in particular contributed about 25 ppm DOC over all zinc ranges tested. In contrast, DOC imparted by the other organic media (2-7 ppm for the CSF® and 10 ppm or more for the SBH) dropped during successive tests. Hardness was relatively unchanged by all media except the sponge and the SBH, which reduced hardness by 21% to 48%. The CSF® media increased hardness by only a few percent. In contrast, the SBH media consistently *removed* about 60 to 80 ppm hardness from the influent, resulting in about a

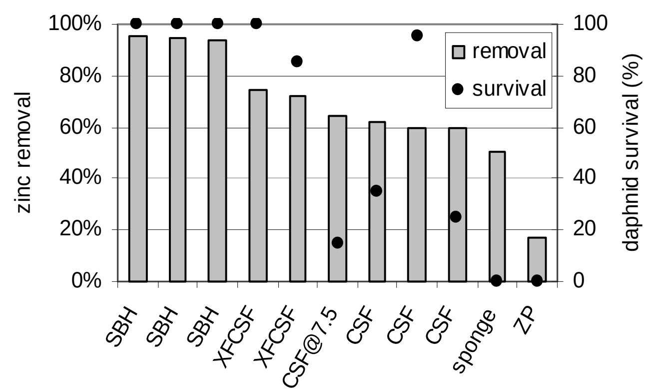

Figure 2 Media Performance at Mid Range (250-500 ppb zinc)

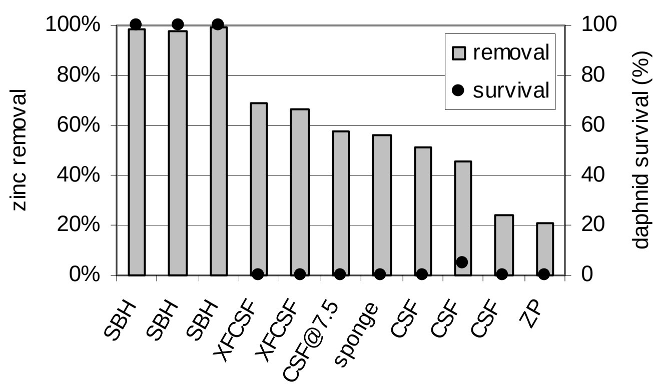

Figure 3 Media Performance at High Range (800-1700 ppb zinc)

70 to 80% decrease overall. The sponge media also removed hardness, but less so than the SBH media. This reduction in hardness is likely due to the high affinity these two media have for divalent metals like calcium and magnesium, in addition to zinc.

Quality Control

Three levels of QC sampling showed acceptable results indicating effective sampling procedures and representative data. Effluent zinc in controls for each medium varied by only a few ppb from influent control concentrations except for the SBH medium, which appeared to add from 14 to 37 ppb zinc, mostly in particulate form. In the influent controls, zinc ranged from <5ppb to a maximum of 24 ppb, pH ranged from 7.0 to 7.4, hardness ranged from 74 to 96 mg/l as $CaCO_3$, and DOC ranged from 0.3 to 0.5 mg/l. Daphnid survival was 100% in all eleven of the influent controls. In the effluent controls, daphnid survival was 95 to 100% for all media except for the sponge, which exhibited zero survival. These results suggested that the sponge apparently generated considerable toxicity, hinted at by the foam, odor and yellow color in the effluent.

CONCLUSIONS

All of the media tested showed some degree of dissolved metals removal, though it was most pronounced for the organic media. The SBH media performed exceptionally well, removing 80 to 90% of the zinc, with up to 99% removal for the highest (4.4 mg/l) zinc influent. Compared to the other media, the SBH effluent zinc concentrations were consistently low (20-40 µg/l) over all ranges tested. Despite achieving these low zinc concentrations, the SBH media needs pH buffering to prevent pH-induced toxicity. In this case, the CSF® media is a suitable pH buffer, and will provide metals removal as well. The CSF® media performed well over the low and mid concentrations tested. Enhancements of the basic CSF® media (lower flow rates and extra fine) achieved modestly improved results. Because media suited for one application (e.g. industrial wastewater) may not always be suitable for others, they should first be screened for inherent toxicity before consideration as a stormwater BMP.

The organic-based media (CSF®, sponge, SBH) added considerable DOC, while the mineral-based medium (zeolite/perlite) did not. Adding DOC would be favorable because of its potential to bind with dissolved metals, reducing their bioavailability and hence reducing toxicity. Compared to the organic media, the mineral based medium did not provide enough dissolved zinc removal to warrant further testing. The highly dissolved zinc fractions tested may under represent the particulate metal removal capabilities for the zeolite/perlite mixture, and certainly do not reflect on zeolite's well-known nutrient removal ability. Finally, though these are laboratory data, the results suggest that the metric typically used to rate BMP performance, that is, percent metals removal (based on influent/effluent concentrations) may not be sufficient to judge performance relative to the toxicity endpoints that are the basis for water quality standards for metals.

ACKNOWLEDGEMENTS

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REFERENCES

ASCE 1999. Determining urban stormwater best management practice (BMP) removal efficiencies. Urban Water Resources Research Council of the American Society of Civil Engineers. WA DC. http://www.asce.org/waterresources/nsbmpd.cfm

CWP 2000. National pollutant removal performance database for stormwater treatment practices. Center for Watershed Protection. Maryland.

Stormwater Management 1999. Stormfilter Product Manual, Version 2.2. Stormwater Management, Portland OR. April 1999.

Port of Seattle 2000. Stormwater Whole Effluent Toxicity (WET) Testing at Seattle-Tacoma International Airport: Final Report. May 2000

Tobiason et al, 2000. Stormwater Whole Effluent Toxicity (WET) testing and source tracing at Sea-Tac International Airport. In the Proceedings of the 73rd Annual Conference of the Water Environment Federation, Anaheim, CA. October 2000.

Marshall et al. 1999. Enahanced metal adsorption by soybean hulls modified with citric acid. W.E. Marshall, L.H. Wartelle, D.E. Boler, M.M. Johns, and C.A.Toles. Bioresource Technology 69 (1999) 263-268.

Marshall et al. 2000. Metal ion adsorption by soybean hulls modified with citric acid: a comparative study. W.E. Marshall, L.H. Wartelle, D.E. Boler, and C.A.Toles. Environmental Technology, Vol 21. 601-607. 2000.

USEPA. 1993. Short-term Methods for Estimating Acute Toxicity of Effluents and Receiving Waters to Freshwater Organisms and Marine Organisms. United States Environmental Protection Agency. August 1993. EPA/600/4-90/027F.

Wartelle and Marshall 2000. Citric acid modified agricultural by-products as copper ion adsorbents. L.H. Wartelle and W.E. Marshall. Advances in Environmental Research 4 (2000) 1-7.

WDOE 1998a. Whole Effluent Toxicity (WET) Evaluation Summary. Publication # 98-03. Washington Department of Ecology. February 1998.

WDOE 1998b. Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria. Publication # WQ-R-95-80. Washington Department of Ecology. Revised December 1998.