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Biochar for stormwater treatment

Biochar is a carbon-negative, low-cost material with promising application in stormwater filtration units. It has already been shown to effectively remove contaminants, including copper and zinc, at two ports in the US state of Washington, Faculty Research Assistant **Myles Gray** from Oregon State University reports.

Recent stormwater projects in the Pacific Northwest are testing the limits of an innovative, green stormwater treatment approach. The projects use biochar, a carbon-negative byproduct of biomass energy production, to remove contaminants from stormwater. Biochar can be used in different filter configurations and has unique chemical and physical properties that endow it with excellent contaminant removal capacity.

At the Port of Port Townsend (PoPT) in Washington, United States, biochar filtration units installed in November 2014 help the site achieve compliance with its stormwater discharge permit benchmarks for copper and zinc. The project included laboratory testing to optimize the biochar filtration media, pilot testing of two filtration devices, and final installation of 18 proprietary roof downspout treatment devices plus two custom, built-in-ground treatment units. Results to date show that the downspout treatment devices are removing more than 95 percent of both copper and zinc from target rooftops.

The success of this and other projects have generated interest among stormwater professionals and the research community about biochar. The unique properties of biochar and the nascent nature of the technology mean that standard solutions are not yet available. Instead, biochar stormwater projects need to be carefully designed and pilot tested to ensure success.

A closer look at biochar

Biochar looks a lot like charcoal – but it's not meant for grilling. Instead, biochar is a byproduct of energy produced by burning plant and animal materials, or biomass. It can be used for a wide range of environmental applications, and can be produced from just about any biomass. It also has properties that make it useful for removing contaminants from water and soil, increasing water and nutrient retention in soils, and controlling odors and vapors. In many ways, biochar can be thought of as a cheaper alternative to activated carbon that can be used in lower-cost applications.

Biochar also is resistant to decay in the environment, lasting for hundreds to thousands of years, thereby sequestering carbon from the atmosphere and rendering the biomass energy carbon-negative. Therefore, the biochar strategy is a resource management approach that achieves three simultaneous goals: the production of renewable biomass energy, sequestration of atmospheric carbon, and production of environmentally beneficial products.

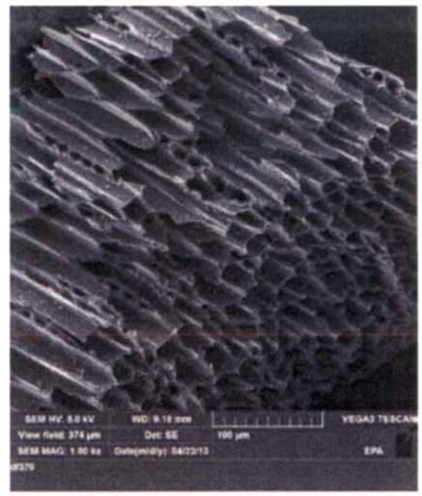
A SINGLE TABLESPOON OF BIOCHAR CAN CONTAIN MORE THAN 400 SQUARE METERS OF SURFACE AREA – APPROXIMATELY THE SIZE OF A RESIDENTIAL CITY LOT.

Biochar's effectiveness in environmental applications is derived from its unique physical and chemical properties. Most importantly, biochar boasts a truly astounding amount of porosity and surface area. It retains the physical structure of the original biomass and can be more than 90-percent porous by volume. A single tablespoon of the material can contain more than 400 square meters of surface area – approximately the size of a residential city lot. The surface area is mostly located in nanometer-sized pores, which are about 10 to 20 water-molecules wide and where pollutants become trapped. The surfaces themselves are chemically complex, allowing the material to attract a range of contaminants.

Technically speaking, biochar removes contaminants from water via several mechanisms, including physical filtration, adsorption, chemical precipitation, and ion exchange. Multiple removal mechanisms provide redundancy and versatility, making biochar attractive for several types of treatment including media filter configurations and incorporation in biofiltration soil mixtures for low impact development.

Over the past ten years, university research teams have demonstrated that biochar can remove many contaminants from water including: nutrients such as ammonia and phosphate; heavy metals including copper, zinc, lead, cadmium, cobalt, and nickel; organic contaminants including polycyclic aromatic hydrocarbons and polychlorinated biphenyls; and trace organics such as herbicides, pesticides, and pharmaceuticals.

Laboratory and field research shows that biochar is especially effective at removing dissolved copper and zinc from water. These contaminants are of particular concern to the stormwater community due to tightening National Pollutant Discharge Elimination System (NPDES) benchmarks. In the Pacific Northwest streams, these contaminants increase mortality rates of endangered native salmon.



A Scanning Electron Microscope image of wood biochar shows how the biochar has retained the physical structure of the original biomass as well as its extensive porosity and surface area. Image by Myles Gray

Port of Port Townsend

PoPT is one of the last remaining ports in the Puget Sound area that provides space for crews to work on their own vessels, drawing boats from as far away as Alaska. The combination of boat maintenance and galvanized (zinc-coated) roofs contribute to high levels of copper and zinc in stormwater runoff that flows into Puget Sound.

To reduce pollutants in stormwater runoff, PoPT elected to explore the use of biochar as a green stormwater filtration alternative. The project was a collaborative effort between PoPT; the engineering consulting firm Landau Associates; a leading company in biochar filtration, BioLogical Carbon, LLC; a local small business, Jofran Enterprises Inc.; and a technical consulting group, Biochar Filtration Solutions. For the project, biochar was generously donated and processed by the neighboring Port Townsend Paper Corporation (PT Paper), which historically considered the material a waste product.

The project began with initial laboratory testing of the PT Paper biochar to characterize and optimize filtration media for removal capacity of zinc and copper. The developed filtration media removed more than 99 percent of both dissolved copper and zinc from stormwater in column tests.

Column tests were then scaled up to a pilot test of onsite roof runoff treatment. In April 2014, a proprietary upflow filtration device was developed and installed at PoPT. The device treated downspout discharge with copper and zinc removal rates of 94-percent and 99-percent, respectively, over three sampling events.

PoPT then implemented a comprehensive site plan that included 18 biochar upflow filtration units to treat roof runoff. The plan also included installation of bulk biochar media in two custom, built-in-ground vessels to treat surface runoff.

Funding for the project was partially provided by a grant from the Washington Department of Commerce, and the project was completed in November 2014. A comprehensive monitoring plan is in place, with results expected by Spring 2015.

Port of Tacoma

The Port of Tacoma, also in the state of Washington, is one of the largest timber exporting ports in the nation with tens of millions of board feet exported annually. Piles of logs and lumber in constant motion at the port combine with general industrial activity and regular rainfall to produce high pollutant loads in stormwater runoff. In 2010 and 2011, the site recorded exceeded stormwater permit benchmarks for zinc, copper, total suspended solids, and chemical oxygen demand.

A recent project at the port used biochar filtration as part of a treatment train approach targeting stormwater pollutants. The project, completed in December 2013, was designed by Kennedy/Jenks Consultants using biochar sourced from Biochar Supreme, Inc. To date, the system has removed an average of 93 percent of monitored pollutants from stormwater discharges.

The port worked with Kennedy/Jenks Consultants to plan and design a stormwater system to treat runoff from approximately 10 hectares of heavy-use area. After considering a total of six treatment alternatives, the port settled on a biofiltration treatment train approach that would utilize four basins in series to remove pollutants.

The second basin was designed to remove heavy metals and chemical oxygen demand using a media mixture of sand and biochar. Preliminary laboratory column testing showed that biochar was just as effective as activated carbon for removing copper and zinc. Due to its substantially lower cost, biochar was chosen over activated carbon for the second treatment basin.

Results from the project show that the treatment system has been performing exceptionally well, achieving contaminant reductions of 94 percent for zinc, 82 percent for copper, 81 percent for chemical oxygen demand, and 98 percent for total suspended solids.

Oregon State University media optimization

At Oregon State University, researchers are focusing on optimizing biochar-based stormwater filtration media to remove copper and zinc from stormwater, with the end goal of promoting successful deployment and commercialization of these products. Researchers have been working in conjunction with Sunmark Environmental Inc. and BioLogical Carbon, LLC – two Oregon small business that have pioneered the use of biochar in stormwater filtration.

Preliminary testing involved biochars sourced from across the Pacific Northwest. With an eye on commercialization, the goal was to source biochars from suppliers with large, consistent supplies.

A rapid screening process was used to identify biochars likely to be useful for stormwater filtration. Biochars that passed the first round of screening were tested for copper and zinc removal capacity. The final step involved creating media mixtures with other natural materials to create complete filtration mixtures that are both effective and affordable.

Currently, Oregon State University researchers have produced biochar-based filtration mixtures capable of removing more than 95 percent of dissolved copper and zinc from stormwater. Contaminant breakthrough testing is underway to determine filter longevity. Future goals for the project include broadening the testing to include removal of other contaminants and to secure state regulatory approval as a best management practice.

Design considerations

Biochar stormwater treatment systems are promising, but effective systems must be carefully designed to account for the unique properties of specific biochars.

All biochar is not created equal

Biochars are diverse; physical and chemical properties depend on feedstock selection and production temperature, among other factors. For instance, biochars made at high production temperatures greater than 500 degrees Celsius from high-carbon feedstocks such as wood or nutshells tend to be the most effective at removing contaminants.

To ensure effective filtration, laboratory contaminant removal trials should be completed prior to any installation. Some biochar suppliers have completed this type of testing for different contaminants or may be able to conduct specific contaminant removal trials.

From a water quality perspective, pH is a critical biochar property. Nearly all biochars are alkaline due to mineral ash compounds within the material. This causes an increase in stormwater pH as it flows through the material, which can help to remove dissolved heavy metals by inducing chemical precipitation. However, some biochars can increase stormwater pH to unacceptable levels – to those above pH 9. To avoid excessive pH increases, extremely high pH biochars should be avoided or mixed with secondary components to stabilize effluent pH.

> CURRENTLY, OREGON STATE UNIVERSITY RESEARCHERS HAVE PRODUCED BIOCHAR-BASED FILTRATION MIXTURES CAPABLE OF REMOVING MORE THAN 95 PERCENT OF DISSOLVED COPPER AND ZINC FROM STORMWATER.

Hydraulics – flow rate control

Control of material flow rates can be a big challenge in implementing successful biochar stormwater filtration. Raw biochar often contains particle sizes ranging from fine dust to chunks resembling the original biomass. Materials with broad size distributions readily clog when used in filtration, as smaller particles migrate and form plugs within the media. Therefore, biochar must be processed after production to be suitable for use in high-flow-rate applications. This can be accomplished by screening or rinsing the biochar and can be customized to create specific particle size mixtures. Some biochar suppliers produce specific particle-size-distribution mixtures that can achieve high-flow rates without additional processing.

Secondary components

In most projects, biochar is mixed with secondary media components to enhance contaminant removal of specific pollutants, increase media flow rates, stabilize effluent pH, and reduce cost. The options for secondary components are extensive and include widely used stormwater treatment media such as zeolites, sand, and peat.

Biochar is extremely light because it is so porous – a dry cubic meter of the material can weigh less than 130 kilograms. This may cause problems when biochar is mixed with denser components, causing media segregation during transportation, installation, and operation. To avoid this problem, it is best to source biochar blends made with similar density components.

The success of the port projects shows that biochar-based stormwater filtration can be an effective treatment approach. However, given the innovative nature of this approach, off-the-shelf solutions do not yet exist, and successful treatment systems must be carefully designed to account for the properties of specific biochars.

Author's Note

Myles Gray is a stormwater researcher at Oregon State University who focuses on innovative treatment methods for contaminant removal. He previously worked in environmental consulting with a focus on contaminant remediation. He holds a bachelor's of science in Geological Sciences from Cornell University and a master's of science in Soil Science and Water Resources Engineering from Oregon State University.