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BIOCHAR FOR WASTEWATER TREATMENT – A MINIREVIEW

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Introduction

Wastewater is important to treat regardless of whether it is to be reused for any purpose or whether it must be treated to reduce the pollution load on the recipient. In urban areas, wastewater is in many cases treated in conventional wastewater treatment plants, but in the country side, these will be unfeasible for the treatment due to high costs. Other solutions have been sought for and one of these is the use of filter materials. The filter materials have been used for removal of various pollutants in different kinds of wastewater and a wide range of filter materials (natural products, industrial waste products or man-made products) have been investigated. Among these filter materials, biochar has attracted increasing attention during the last decade (Rosales *et al.,* 2017). A large number of publications related to biochar are dealing with the production or properties of biochar, while others are dealing with the potential applications of this material, see review by Xie et al. (manuscript). Many researchers seem to agree that biochar is a feasible way to remove pollutants of different kinds from wastewaters ending up in conventional wastewater treatment plants (Sylwan et al., 2020) or in small-scale treatment facilities.

Qambrani *et al*. (2017) state that the use of biochar for removal of pollutants from wastewater is a new and promising application, a statement which is supported by Rosales *et al*. (2017) who claims that the use of bio chars for wastewater treatment requires the development of engineered systems in full-scale. Several other scientists have also suggested wastewater treatment by biochar as suitable for wastewater treatment. A number of articles have focused on removal of pollutants commonly found in wastewater, e.g. nutrients, heavy metals, organic matters and pharmaceuticals (Ahmed *et al*., 2015; Inyang *et al*., 2016; Tan *et al*., 2015). The majority of these experiments, based on various types of biochar produced under different thermochemical conditions, have been performed using aqueous solutions, often spiked with a specific pollutant in various concentrations. These investigations have revealed new knowledge about sorption capacities of biochar and properties of importance for sorption of a wide range of pollutants. However, many researchers agree upon the fact that the origin of the feedstock and the thermochemical treatment method are tightly connected and will have an impact on the properties of the biochar (Xie et al., manuscript).

Results

There are investigations where biochar with various origin have been used, solely or mixed with another media, for removal of various pollutants from real-life wastewaters of different kinds, see Table 1.

From the table it can be seen that researchers have investigated different kinds of biochar under various conditions using different kinds of wastewaters with regard to a wide range of pollutants ranging from nutrients (Zhou *et al*., 2018; Zhang *et al*, 2013; Rozari *et al*., 2015, 2016, 2017; Gupta *et al*., 2016; Sun *et al*., 2018) to pharmaceuticals (Shimabuku *et al*., 2016), *E. coli*. (Mohanty *et al*., 2014; Lau *et al*., 2017; Rozari *et al*., 2015) and organic matter (Gupta et al., 2016; de Caprariis et al., 2017). The knowledge of the use of biochar used for wastewater treatment can therefore be said to be scattered. There are however a few factors that could be discussed a bit further, e.g. the feedstock, its transformation to biochar and the properties of the biochar, the different wastewaters and their contents of pollutants.

Table.

Biochar tested for laboratory made or real-life wastewater with regard to pollutants targeted

<table>
<tr><th>Type of biochar</th><th>Type of wastewater</th><th>Targeted pollutant</th><th>Experimental set-up</th><th>Reference</th></tr>
<tr><td>Forestry waste</td><td>Surface water, waste-water, storm water</td><td rowspan="9">Sulfamethoxazole (SMX)</td><td rowspan="9">Batch tests</td><td rowspan="9">Shimabuku et al., 2016</td></tr>
<tr><td>Forestry waste</td><td>Wastewater</td></tr>
<tr><td>Wood cuts (eucalyptus)</td><td>Surface water</td></tr>
<tr><td>Wood cuts (pine)</td><td>Surface water, wastewater</td></tr>
<tr><td>Bio solids</td><td>Surface water, waste-water, storm water</td></tr>
<tr><td>Dissolved air flotation thickened solids</td><td rowspan="4">Surface water, wastewater</td></tr>
<tr><td>Primary digester sludge</td></tr>
<tr><td>Secondary digester sludge</td></tr>
<tr><td>Human faecal material</td></tr>
<tr><td>Wood chips Sonoma</td><td rowspan="3">Synthetic storm water</td><td rowspan="3">E. coli</td><td rowspan="3">Column experiments</td><td rowspan="3">Mohanty et al., 2014</td></tr>
<tr><td>Wood chips (low-temp. pyrolysis)</td></tr>
<tr><td>Wood chips (high temp. pyrolysis)</td></tr>
</table>

Table continued.

Wood waste (*Acacia confusa* and *Celtis sinensis*)	Synthetic storm water	*E. coli*	Column experiments	Lau *et al*., 2017
Wood /lodge pole pine wood)	Real industrial wastewater (brewery wastewater)	COD_{-T}, COD_{-D}, TSS, PO_4-P, NH_4-N	Batch tests, Packed bed column tests	Huggins *et al.*, 2016
Bamboo	Synthetic wastewater	NH_4-N, COD	Microcosm constructed wetlands	Zhou *et al*., 2018
Raw corn	Synthetic wastewater	PO_4-P	Batch tests (?)	Zhang *et al*., 2013
Corn straw	Domestic wastewater	COD, NH_4-N, TN	Subsurface waste-water infiltration system (column size)	Sun *et al*., 2018
Hardwood mixed with other media	Secondary clarified wastewater Septage	BOD, SS; *E. coli*, P, N	Vertical flow mesocosms	Rozari *et al*., 2015; Rozari *et al*., 2017; Rozari *et al*., 2018
Oak tree (*Quercus sp*.) mixed with other media	Synthetic wastewater	Organic matter, N, P	Mesocosm scale horizontal surface flow constructed wetlands	Gupta *et al.*, 2016
Poplar wood (high and low temp.pyrolysis)	Pyrolysis wastewater	Organic matter (see de Caprariis *et al.*, 2017)	Batch tests	de Caprariis *et al.* (2017)

From the literature (Xie et al., manuscript) it can be concluded that a large number of different feedstock material have been used to produce biochar, for instance wood or wood residues, garden wastes or human and animal wastes. These feed stocks can be transformed into biochar by torrefaction and pyrolysis and also through other less common methods. Depending on transformation method, the biochar will get different properties and depending on properties, the biochar might be more or less suitable for removal of specific pollutants. Rosales *et al*. (2017) report that the chemical composition of the biochar surface is of importance for the removal of nitrogen. The chemical composition of the surface is determined by the pyrolytic temperature, at low-temperature pyrolysis, the biochar will get a high content of groups containing oxygen which will increase the cation exchange capacity (CEC), thus increase the removal of N. Acidic and functional phenolic and carboxyl groups are assumed to promote ammonium (Rosales et al., 2017). Further on, Rosales *et al*. (2017) list properties of importance related to the removal of heavy metals. These properties include more specifically surface area, porosity, pH, surface charge, functional groups and mineral components, and in addition, the target metal to be removed. As examples, Rosales *et al.* (2017) mention removal of mercury (Hg) is favoured by a high specific surface area and less functional groups and that removal of copper (Cu) is favoured by Si and PO_4^{2-} particles on the biochar. Further on, a large number of oxygen-containing groups will increase the removal of cadmium (Cd). The properties mentioned above thus contribute to a vast number of mechanisms that are responsible for the metal removal, e.g. electrostatic interaction between the surface of the biochar and the specific metal, the CEC between metals and protons and the alkaline metals on the surface of the biochar, metal complexation with functional groups and precipitation of metals that form non-soluble compounds. According to Rosales *et al*. (2017) several investigations have been made, using different types of biomass feedstock and production methodologies to enhance the metal removal capacities of biochar through modification. The modification methods have varied depending on the targeted metal. Regarding pharmaceuticals, Peiris *et al*. (2017) mention three major properties of biochar that are of importance for the removal of various pharmaceuticals. These are sorption affinity, sorption capacity and sorption dynamics. Specific properties of the tested biochar presented in Table 1 are not mentioned by the researchers, one can only assume that the properties of the particular biochar tested are somewhat similar to results from other investigations in which a specific biochar has been investigated with regard to its properties and the importance of these for a specific pollutant, e.g. a single-metal solution for instance.

The various types of wastewaters investigated also contribute to the scattered knowledge. Different types of wastewaters have been used in the studies presented in Table 1, e.g. real-life wastewaters (Shimabuku *et al.*, 2016; , storm waters (Shimabuku *et al.*, 2016; Rozari *et al.*, 2015, 2017; 2018) , industrial (Huggins *et al*., 2016), agricultural and pyrolysis (de Caprariis *et al*., 2017) wastewaters as well as synthetic wastewaters (Zhang *et al.*, 2018; Mohanty *et al.*, 2014; Lau *et al.*, 2017; Zhang *et al.*, 2013). Even within each category of wastewater, the composition might vary widely, for instance, Wei *et al*. (2018) describe the complexity of various agricultural wastewaters.

The types of test-set ups mentioned in Table 1 also varies between studies. Batch tests are different from column studies and mesocosm constructed wetland experiments, the former are for instance easier to control with regard to different parameters such as temperature and light which have proven to effect P-removal by various filter materials (Johansson Westholm, 2006). Column experiments as performed by Mohanty *et al*. (2014) and Lau *et al*. (2017) might also be easier to control since these often are performed in a laboratory environment where parameters can be controlled.

Those researchers who have used mesocosm wetlands systems have used biochar as an addition to some other media in order to increase the removal of the targeted pollutant(s). Gupta et al. (2016) could report a more efficient removal of pollutants (COD, TN, NH_3, NO_3-N, TP and PO_4) when adding biochar to the wetland systems and they attributed this to a larger specific surface area provided by the biochar. Rozari *et al*. (2017) also reported that the addition of biochar enhanced the removal of nitrogen from both secondary clarified waste-water and septage. On the other hand, Rozari *et al.*, (2015) found that the addition of biochar did not improve to removal of BOD, suspended solids and coliforms when using secondary clarified wastewater in the experiments.

Conclusions

In the light of the above mentioned, it can be concluded that the knowledge of the use of biochar for removal of pollutants are scattered. Different types of biochar, produced under various conditions, have been tested which makes it more or less impossible to compare properties of the biochar investigated. The number of articles on biochar and its use for removal of pollutants from wastewaters are however increasing, thus the knowledge will follow the same pattern and continuing with this research will be beneficial since biochar seem to be promising.

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