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Performance of a two-phase biotrickling filter packed with biochar chips for treatment of wastewater containing high nitrogen and phosphorus concentrations

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ABSTRACT

A two-phase biotrickling filter (BTF) system with sequential aerobic and anaerobic flow cell reactors was evaluated for treating nitrogen/phosphorus-rich wastewater using packing material consisting of biochar manufactured from porous palm residues. The filter system was seeded with microbial consortia from the freshwater sediment with a history of exposure to fertilizer runoff. For test purposes, the BTF was fed with simulated wastewater and operated under variable aerobic and anaerobic conditions using various carbon sources and loading conditions. Start-up and operation characteristics including hydraulic retention time (HRT), carbon sources and reactor column depths on pollutants removal were studied. The BTF began working well after one month of operation and thereafter provided effective treatment. Optimal operation parameters utilized an HRT of 36–48 h, using bicarbonate as carbon source, and palm biochar chips as the packing material. Sequential aerobic nitrification and anaerobic denitrification were obtained with NH_4^+-N and TP/NO_x-N being removed in Reactor A and Reactor B, respectively. The results showed that the two-phase BTF system was efficient for treating wastewater with high concentrations of nitrogen and phosphorus: Under optimum conditions, removal of approximately 80% of ammonium and 68% of total phosphorus was achieved, resulting in the formation of effluent suitable for recycling or release into natural waters. The study provides invaluable insight for further design and operation of full-scale wastewater treatment system.

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1. Introduction

Biotrickling filters have been successfully used for removing diverse organic and inorganic pollutants from contaminated gaseous and liquid effluents generated by different industries. Many prior studies illustrate the practical significance and efficiency of the process (Goncalves and Govind, 2008; Kong et al., 2001; Lebrero et al., 2012; Li, 2013; Pearce, 2004; Tsang et al., 2008). In such bioreactors, the selection of appropriate packing materials is important for achieving immobilization, growth, and activity of the microorganisms that carry out the treatment process. Physicochemical properties of the packing material also strongly influence hydrodynamics and bioavailability of the contaminant for degradation (Iffat et al., 2015; Ji et al., 2015; Krüner and Rosenthal, 1983; Sharvelle et al., 2008; Wang et al., 2006; Yue et al., 2009). In this regard, support materials based on charcoal, activated carbon, or biochar amendments are generally considered as cost-effective sorbents for some pollutants and facilitate biodegradation and biotransformation of pollutants as they pass through the filter. Biochar materials vary considerably in their physicochemical properties, depending on the feedstock and pyrolysis conditions that are used to create the materials. Selection of a biochar feedstock is highly dependent on the purpose for which it is being used. Some biochar materials have long been used to remove impurities and pollutants from aqueous systems: including for example, removal of heavy metals, phosphorus, antibiotics, and sorption of organic pollutants. Biochar materials derived from crop residues are particularly attractive for contaminant removal, given their low cost and potential adsorption capacity for various pollutants from aqueous or gaseous environment (Ippolito et al., 2012; Novak and Busscher, 2012; Yao et al., 2012; Zhang et al., 2012).

Wastewaters containing high levels of nitrogen and phosphorus from both point and non-point sources are major causes of eutrophication in many freshwater and estuary ecosystems. For example, both NH_4^+-N and TP are typical contaminants in biogas slurries generated during anaerobic treatment of manure from intensive piggery operations. In the long run, the direct discharge or irrigation of the biogas slurries could degrade surrounding waters and impose severe risk to the ecosystem (Li et al., 2013). It is therefore very important to explore cost-effective technologies for removal of nitrogen and phosphorus from aqueous environments prior to runoff and discharge into natural waters. Nitrifying trickling filters (NTFs) have been successfully used for removal of ammonia as well as removal of metals from ground and surface waters (Coats et al., 2010; Eding et al., 2006; Sakuma et al., 2008; Tekerlekopoulou et al., 2010; Ben et al., 2008; Yang et al., 2005). Using a two-stage, sequential aerobic–anaerobic treatment system, NH_4^+ can first be converted to NO_3^- in the presence of oxygen, and then denitrified by conversion to N_2 and NO_x gases under anaerobic conditions when nitrate is used as an electron acceptor for microbial respiration. The first process is chemoautotrophic, whereas denitrification requires a carbon source to generate electrons required for the reduction of NO_3^-.

In the present study, the development of a two-phase biotrickling filter (BTF) packed with palm biochar chips for the effective treatment of high ammonia/phosphorus wastewater is described. Start-up and operation characteristics of the system were studied. Impact of hydraulic retention time (HRT), different carbon sources and different column depth on bioreactor performance (NH_4^+-N and TP removal) were also determined for a BTF that was acclimated and then run continuously over an extended time period.

Table 1 – The characteristics of packing materials.

Packing materials	Unit	Palm biochars
Shape	–	Chips
Size	mm	5.00 × 8.00
Temperature of pyrolysis (*T*)	°C	700.00
Yield (*Y*)	%	28.14
Carbon (C)	%	62.74
Hydrogen (H)	%	1.13
Nitrogen (N)	%	0.72
Specific surface area (SA)	m^2/g	417.85
Total pore volume (TPV)	cm^3/g	0.22
Average pore radius (APR)	nm	2.08
True density (TD)	g/cm^3	2.11
Porosity	%	62.79
pH-value	–	10.36

2. Materials and methods

2.1. Packing materials

Palm residues from leaf sheaths were used for preparation of biochar chips under anoxic pyrolysis conditions of 2 h at 700 °C and nitrogen atmosphere. Biochar was sieved to remove dust and obtain chips with an irregular size of approximate 5.0 × 8.0 mm that were used as the packing materials for the two-phase BTF. The pH of biochar was determined for a 1:20 suspension of biochar in deionized (DI) water after shaking and equilibration for 5 min before measurement with a pH meter (Fisher Scientific Accumet Basic AB15). Elemental C, N and H abundances were determined using a CHONS Elemental Analyzer (Elementar, Vario EL cube) via high-temperature catalyzed combustion followed by infrared detection of the resulting CO_2, H_2 and NO_2 gases, respectively. The specific surface area (SA) and average pore radius (APR) of the biochars were determined by multipoint Brunauer–Emmett–Teller (BET-N_2) analysis of adsorption data points with 0.01–0.99 relative pressure range of the N_2 adsorption isotherm at 77 K. The total pore volume (TPV) was estimated from a single N_2 adsorbed point at a relative pressure of about 0.99 (Quantachrome QuadraWin QuadraSorb SI, ASIQMO002-2, USA). The True Density (TD) and Porosity were determined by True Density Meter (Quantachrome, VPY-30) (Table 1).

2.2. Microbial consortia

The microbial consortia for bioreactor inoculation were isolated from the sediment of a freshwater pond located in the University of California, Riverside Botanical Gardens, USA. The consortia were selected from the sediment community by enrichment culture in 250 mL Erlenmeyer flasks containing 100 mL of mineral medium on a rotary shaker at 25–30 °C. After two months of batch enrichment, the cells were harvested, centrifuged and then re-suspended in fresh nutrient medium for use as inocula in the BTF experiments. Three microbial consortia were obtained by acclimation and enrichment: nitrifying bacterial consortium (NBC), denitrifying bacterial consortium (DNBC) and denitrifying phosphorus-accumulating organisms (DNPAO). These consortia were used for start-up of the bioreactor for removing nitrogen and phosphorus from wastewater.