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Wastewater treatment by anaerobic filter and sand filter: Hydraulic loading rates for removing organic matter, phosphorus, pathogens and nitrogen in tropical countries

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ABSTRACT

This study evaluated a wastewater treatment system combining anaerobic filters and sand filters, focusing on the suitability of such system to remove solids, organic matter, phosphorus, and pathogens, as well as the nitrification efficiency of the sand filters employed. The anaerobic filters were filled with shells of coconuts of the species *Cocos nucifera*, while the sand filters included 0.75-meter deep sand beds, exposed to hydraulic loading rates ranging from 100 to 800 $L\,m^{-2}\,day^{-1}$. As a result, we could ascertain that the system has the capacity to receive rates above those suggested as the maximum threshold by a Brazilian standard, namely ABNT (1997), and the U.S. standard (USEPA, 1999). A minimum removal of 95% of COD and BOD was found, regardless of the hydraulic loading rates used. The only parameter evaluated that showed a significant difference in the means found was nitrogen. At a hydraulic loading rate of 700 $L\,m^{-2}\,day^{-1}$, the concentration of $N—NH_4^+$surpassed that of nitrate, pointing to the loss of nitrification efficiency. On account of this, this compound should be considered the reference parameter to ascertain the hydraulic loading threshold connected to the anaerobic effluents flown into sand filters.

1. Introduction

Estimates are that over 82% of the developing countries' rural population has access to poor sanitation services (Massoud et al., 2009). In Brazil, around 31 million persons live in the countryside (IBGE, 2010), and most of these people dispose of their waste directly into water streams or on the ground. As in other developing countries, countrymen have little technical knowledge and low financial resources (Paraskevas et al., 2002), and this inhibits the installation of sophisticated and costly wastewater treatment systems (Cruz et al., 2013).

In response to this sanitary condition, the Brazilian government launched PROSAB (the Basic Sanitation Research Program). One of its core goals was to further research on the sanitation of rural areas. Anaerobic filters filled with bamboo rings (Camargo and Nour, 2001), *C. nucifera* coconut shells (Cruz et al., 2013) or ceramic bricks (Chernicharo, 2006) were some of the reactors tested. Uncomplicated to build and inexpensive, they turned out to be a good wastewater treatment option for small communities which had low population density, and, thus, encouraged the dissemination of decentralized sanitation (Hedberg, 1999; Wilderer and Schreff, 2000).

Cruz et al. (2013) found out that coconut shells could be used as the fillers of anaerobic filters, due to their high resistance to biological degradation. Additionally, coconut shells posted more robust values of empty bed volume (81.3 ± 2.7%) and surface area (100.3 ± 14.8 $m^2\,m^{-3}$) than other low cost materials which are typically employed, such as crushed stone and bamboo rings, and were on a par with industrial materials. Anaerobic effluents reached a BOD of 77 ± 50 $mg\,L^{-1}$, which provided an efficiency of 81 ± 38% over the raw wastewater. Finally, the system allowed simple operation and maintenance.

Besides the treatment efficiency, consistent with that of anaerobic reactors (Foresti, 2002), the effluent measurements failed to meet the standards established by the applicable Brazilian laws (Camargo and Nour, 2001; Cruz et al., 2013).

Therefore, a post-treatment alternative that could ensure low cost and operation friendliness should be sought, and attention was drawn to the intermittent sand filter. This type of filter has its operation based on intermittent influent application on a sand bed

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through a distribution piping. In this apparatus, purification is performed by physical, chemical and biological mechanisms that take place during the filtration (Ausland et al., 2002).

Intermittent sand filter systems —ISF— can be employed to reliably achieve a significant reduction of COD (chemical oxygen demand), TSS (total suspended solids), coliform bacteria and viruses (Gross and Mitchell, 1990; Darby et al., 1996; Emerick et al., 1999). According to Ellis (1987), this reactor allows removing almost 88% of the suspended solids and 76% of BOD (biochemical oxygen demand). In turn, Kang (2004) found out that sand filters also result in greater nitrification of nitrogen compounds. Furthermore, an optimized ISF system allows a secondary to tertiary degree of treatment, facilitating disinfection and water reuse (Asano et al., 2007; Leverenz et al., 2009). Marinho et al. (2013) used the effluents of intermittent sand filters to irrigate crops of rose bushes, employing drip irrigation; and, after two years of research, could not find any cloggings caused by particulates or organic matters.

The Brazilian standard that regulates the building and operation of sand filters (ABNT, 1997) recommends that the hydraulic loading rate should be limited to 100 $L\,m^{-2}day^{-1}$ in anaerobic post-treatment processes. Although it is an environmental agency from a country typically subject to a colder weather, the U.S. Environmental Protection Agency (USEPA, 1999) stipulates a rate higher than that in the Brazilian standard, namely 200 $L\,m^{-2}day^{-1}$.

Therefore, this study evaluated a combination between anaerobic filters filled with coconut shells and sand filters to further understand such this simplified wastewater treatment system and help disseminate this technology in developing countries. The main purpose of this investigation was to substantiate a suggestion about the appropriate threshold of hydraulic loading rate for inflow on the sand filters surface.

2. Material and methods

As described by Cruz et al. (2013), this project was carried out in an area reserved for research efforts at the School of Civil Engineering, Architecture and Urbanism of UNICAMP, in Brazil. The untreated wastewater was collected from the university campus wastewater network, which had part of its outflow routed to four anaerobic filters. The reactors were made of stainless steel, had a cylindrical shape and total volume of 500 L (Fig. 1). The filters were 1.68 m long, with a diameter of 0.76 m. A bamboo grid was used to separate the coconut shells from the conical bottom, and also served the purpose of improving wastewater distribution.

The material used to fill the anaerobic filters was shells of the *C. nucifera* coconut species broken into four pieces, as shown in Fig. 2.

Fig. 2. Shells of the coconut species *Cocos nucifera* (Cruz et al., 2013).

Each reactor required 280 kg of this material to be full. The operation of the anaerobic filters had an upflow and HRT (Hydraulic retention time) of 9 h.

2.1. Sand filters

The effluent from the anaerobic filters was routed to the surface of four sand filters. Before hitting the surface of the sand bed, the liquid collided with splash plates consisting of square plates with 0.20 m in length. This was targeted at improving the spreading over the bed.

The sand filters were built with cylindrical boxes with internal diameter of 1.00 m. The bed was composed of three stratified layers from the reactor's bottom up (Fig. 3). The first one was 0.20 m deep and consisted of gravel with effective size (D_{10}) of 16.12 mm and UC (Uniformity Coefficient) of 45.80 ± 0.40%. The second layer consisted of gravel with D_{10} amounting to 7.51 mm and UC of 1.66, with a depth of 0.05 m. This material supported the sand in such a way to prevent that particles flowed out of the apparatus (Tonetti et al., 2010).

The sand bed was 0.75 m deep, and the sand used had the effective size of 0.18 mm, UC of 3.14, and empty bed coefficient of 28.6 ± 0.9%. To expand the natural aeration of the bed, a vent pipe with internal diameter of 0.050 m and longitudinal holes of 0.025 m was attached on the side of each filter (Fig. 3).

The effluent was added to the anaerobic filter from above the sand beds surfaces at hydraulic loads of 50 $L\,m^{-2}$. It was flown into each of the four sand filters within a short periodicity (SF1, SF2, SF3, and SF4) (Table 1). With the purpose of comparing 10 different

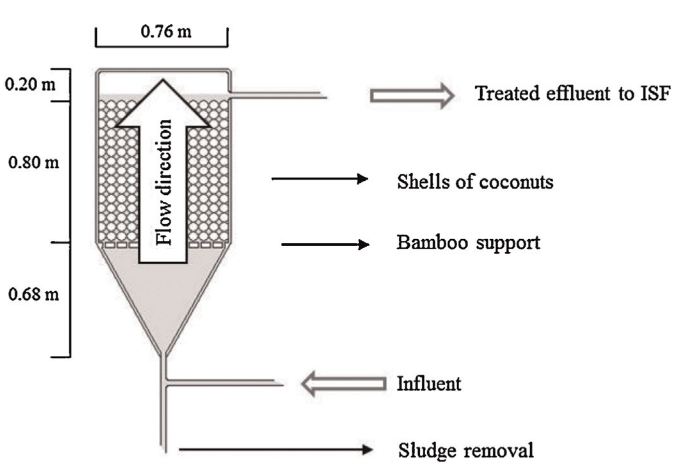

Fig. 1. Scheme of the upflow anaerobic filter (Tonetti et al., 2012).

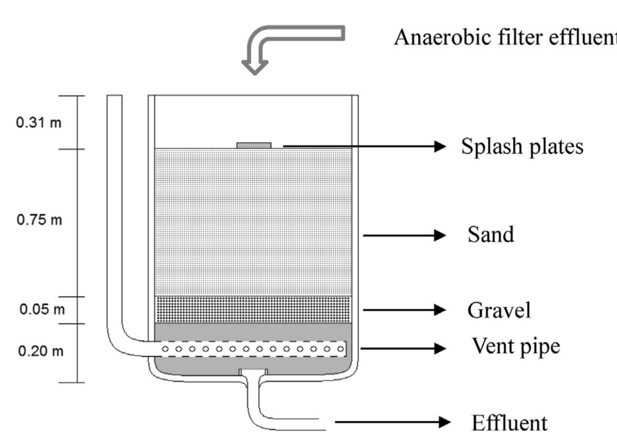

Fig. 3. Scheme of the sand filters.