ARTICLE IN PRESS

Journal of Cleaner Production xxx (2016) 1–7

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Greywater treatment using a moving bed biofilm reactor at a university campus in Brazil

Mariana Cardoso Chrispim [b,*], Marcelo Antunes Nolasco [a,b,**]

[a] School of Arts, Sciences and Humanities, University of Sao Paulo, Av. Arlindo Bettio 1000, Sao Paulo, SP, 03828-000, Brazil
[b] Graduate Program in Sustainability, University of Sao Paulo, Av. Arlindo Bettio 1000, Sao Paulo, SP, 03828-000, Brazil

ARTICLE INFO

Article history:
Received 28 January 2016
Received in revised form
24 July 2016
Accepted 25 July 2016
Available online xxx

Keywords:
Water reuse
Greywater
Sustainable sanitation
Biological reactor
Water conservation
Sustainability

ABSTRACT

Water reuse can contribute as an important approach and practice to the reduction of the pressures on water resources lowering the demand for potable water for purposes that do not require water's high quality. However the greywater reuse has been rarely applied in Brazil. Therefore, the main objective of this study was to evaluate a greywater collection and treatment system from lavatories, showers and washing machine aiming the non-potable reuse. The objectives were to characterize the quality and quantity of greywater from different sources, to monitor a pilot system for synthetic greywater treatment and to analyze the quality of the effluent after treatment. The pilot system implemented in a building at University of Sao Paulo allowed to segregate greywater collection and characterization. To evaluate the greywater production water flow meters were installed in the water inlet of each greywater source. The treatment system included a moving bed biofilm reactor and a settling tank at pilot scale. The evaluation of greywater treatment was conducted based on the monitoring of physicochemical and microbiological water quality parameters during the operation of the experimental system. Based on the results, amongst the three greywater sources, the water from showers had the highest *E. coli* concentration while the lavatories water had the highest total coliforms concentration. The removal efficiencies of BOD and COD were 59% e 70% respectively. The phosphorus removal during the experimental period was low. Nevertheless the water quality produced is viable to be applied for outdoor purposes - landscape and garden irrigation in household, commercial and institutional buildings and the results were satisfactory according to Brazilian standard. The treatment showed stability and reliability ensuring the potential for a safe reuse if appropriate operation and monitoring of the treatment system is performed.

1. Introduction

Greywater, the household wastewater produced by showers, baths, lavatoriess, kitchen sinks and laundries, comprises 50–80% of total domestic wastewater (Nolde, 2005). The composition of greywater is affected by many household factors including products used in the household, building infrastructure, and residents' behavior, activities, income and age. Generally, greywater contains low total suspended solids, high turbidity, and high concentrations of phosphorus, surfactants, oils and greases.

Greywater reuse is an important practice because it can reduce municipal wastewater production and lower demand for potable water. Consequently, greywater reuse has the potential to decrease urban wastewater discharge and improve environmental health by reducing environmental impacts such as energy consumption, and water and land pollution. Furthermore, greywater reuse can also reduce the urban infrastructure required for collection, transport and treatment of wastewater. Studies have estimated that greywater reuse has the potential to generate between 25 and 30% savings of potable water consumption in a household (Ferreira and Ghisi, 2007). Treated greywater can be used for non-potable purposes, including toilet flushing, vehicle washing, cleaning purposes, laundry, irrigation, and industrial uses.

Chemical, physical and biological treatment processes, such as adsorption on activated carbon, sand filtration, and membrane bioreactor, have been evaluated for treating greywater. However, common physical processes such as sand filtration followed by disinfection are limited because they can not remove high concentrations of dissolved compounds, and require pretreatment (Li et al., 2009). Several conventional chemical processes can efficiently

* Corresponding author. State University of Mato Grosso do Sul, Street: General Mendes de Morais, 296, Coxim, MS, 79400-000, Brazil. Tel.: +55 (67) 981096804.
** Corresponding author. School of Arts, Sciences and Humanities, University of Sao Paulo, Av. Arlindo Bettio 1000, Sao Paulo, SP, 03828-000, Brazil.
E-mail addresses: mariana_chrispim@hotmail.com (M.C. Chrispim), mnolasco@usp.br (M.A. Nolasco).

http://dx.doi.org/10.1016/j.jclepro.2016.07.162
0959-6526/

Please cite this article in press as: Chrispim, M.C., Nolasco, M.A., Greywater treatment using a moving bed biofilm reactor at a university campus in Brazil, Journal of Cleaner Production (2016), http://dx.doi.org/10.1016/j.jclepro.2016.07.162

remove the suspended solids, organic materials (COD, BOD) and surfactants mainly in the low strength greywater (Lin et al., 2005). Currently, there is a trend to incorporate biological processes for greywater treatment, particularly in densely populated cities. Saumya et al. (2015) evaluated a wetland system for synthetic greywater treatment and found COD and BOD removal to be 39.7% and 70%, respectively, as well as high turbidity removal (92.1%). Couto et al. (2015) evaluated greywater treatment in a Brazilian airport using an anaerobic filter followed by UV disinfection. These authors discussed anaerobic treatment as an alternative to aerobic treatments in order to reduce cost and potentially produce energy. In their study, the treatment processes resulted in 73% and 88% removal of BOD and turbidity, respectively. It is important to note that greywater treatment systems are often complex, involving many units of process equipment. Hence, there is a need to develop greywater treatment systems that can be easily operated and maintained, be compact, low cost and produce good-quality effluent that is safe for reuse (Teh et al., 2015).

Nowadays biofilm based reactors are widely applied in distributed wastewater treatment facilities. Several hundred plants around the world (Shahot et al., 2014; Hosseini and Borghei, 2005) have adopted moving bed biofilm reactors (MBBRs) for multiple wastewater treatment processes. Typical processes include organic matter oxidation and nitrogen removal in municipal and industrial applications. MBBRs have been used in both large and small scale facilities (Rusten et al., 1997).

The MBBR is a biological process based on biofilm attached growth in order to improve efficiencies for organic matter degradation and nutrient removal. The technology was developed in the late 1980s by the Norwegian company Kaldnes MiljØteknologi and has been applied in municipal and industrial wastewater treatment plants in several countries. Inside the reactor there are free-floating carriers that provide protected surface area to support the growth of heterotrophic and autotrophic bacteria. The advantages of MBBRs over other conventional systems include low maintenance and ability to handle fluctuations in high flow rates and changes in the organic load of the raw wastewater (Aygun et al., 2008).

There are few scientific studies focusing on greywater treatment and reuse, particularly addressing the performance of attached growth as a technological solution for biological treatment of greywater. The main objectives of this study are to evaluate the technical feasibility of a greywater collection and treatment system using a moving bed biofilm reactor in order to locally reuse water for non-potable purposes. The specific objectives are to characterize greywater from multiple sources in terms of quality and quantity, to monitor a pilot system for synthetic greywater treatment, to analyze the quality of the effluent after treatment, to compare the pilot system with other greywater treatment processes and to indicate potential non-potable uses for treated water. Considering that greywater may contain chemicals and pathogens, it should be treated before its reuse. Thus, the main goal of the present study was to evaluate a prototype that is compact, easy to maintain and is feasible to use in urban water systems with high population density and lack of available spaces, a common situation in large cities in developing countries.

2. Material and methods

2.1. Greywater characterization

Greywater samples from different sources were collected and characterized for physicochemical and microbiological parameters, including BOD, COD, total organic carbon (TOC) concentration, turbidity, total suspended solids (TSS), total solids (TS), pH, alkalinity, electrical conductivity, oils and grease, total nitrogen (N), total phosphorous (P), sulfate, total coliform and *E. coli* concentrations. These analyses were performed in accordance with Standard Methods for the Examination of Water and Wastewater 21st edition (APHA, 2005). Before collecting samples for total coliform and *E. coli* analyses, the sample bottles were autoclaved at 121 °C under 1 atm for 20 min and water samples were analyzed using 3M™ Mini Flip Top Vial (for dilution) and 3M™ Petrifilm method.

A building designed for the university employees at University of Sao Paulo, Brazil was used for this study. The greywater sources in the campus building consisted of four showers, two lavatoriess and one washing machine. The wastewater collection drains of this building were modified to allow sample collection from different sources separately for qualitative and quantitative characterization. To better evaluate greywater production in the building, interviews were conducted with frequent users and included questions regarding how frequently each greywater source (shower, lavatories, washing machine) was used. Water flow rate meters (Unimag Cyble nominal flow rate: 1.5 m^3/h, Multimag Cyble nominal flow rate: 3.5 m^3/h and Flodis Cyble nominal flow rate: 1.5 m^3/h, Itron) were installed at the water inlet of each greywater source, washing machine, showers and lavatories respectively, to estimate the volume of produced greywater. Greywater generation was monitored for 10 months. Before designing the pilot greywater treatment unit, daily greywater generation by each source was estimated based on interviews and water flow rates.

2.2. Pilot plant set up

The pilot greywater treatment unit (Fig. 1) was built on the outside of the campus building and consisted of three plastic

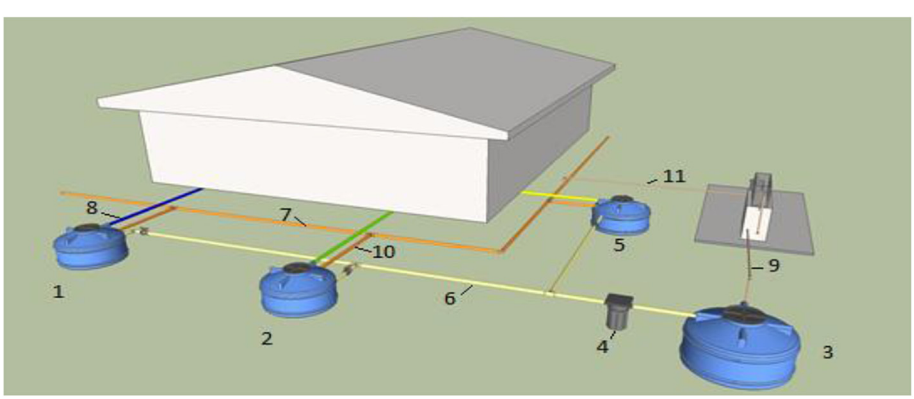

Fig. 1. Pilot greywater treatment system. 1,2,5-tanks for segregated greywater collection (washing machine, showers and washbasins); 4-pretreatment; 3-equalization tank; 6—pipe connections; 7—sewer; 8-pipe collecting greywater from washing machine; 9-greywater from equalization tank being pumped to MBBR reactor; 10-overflow pipe of collected greywater to the sewer network; 11-collecting pipe of treated greywater.

Please cite this article in press as: Chrispim, M.C., Nolasco, M.A., Greywater treatment using a moving bed biofilm reactor at a university campus in Brazil, Journal of Cleaner Production (2016), http://dx.doi.org/10.1016/j.jclepro.2016.07.162