Journal of Environmental Management 176 (2016) 119–127

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Simplified greywater treatment systems: Slow filters of sand and slate waste followed by granular activated carbon

Mariah Siebert Zipf*, Ivone Gohr Pinheiro, Mariana Garcia Conegero

FURB — Fundação Universidade Regional de Blumenau, Rua São Paulo, 3250, Itoupava Seca, Campus II, Bloco I, Sala 103, CEP 89.030-000 Blumenau, SC, Brazil

A R T I C L E I N F O

Article history:
Received 10 November 2015
Received in revised form
21 March 2016
Accepted 22 March 2016
Available online 2 April 2016

Keywords:
Greywater
Treatment
Filters
Slate waste

A B S T R A C T

One of the main actions of sustainability that is applicable to residential, commercial, and public buildings is the rational use of water that contemplates the reuse of greywater as one of the main options for reducing the consumption of drinking water. Therefore, this research aimed to study the efficiencies of simplified treatments for greywater reuse using slow sand and slow slate waste filtration, both followed by granular activated carbon filters. The system monitoring was conducted over 28 weeks, using analyses of the following parameters: pH, turbidity, apparent color, biochemical oxygen demand (BOD), chemical oxygen demand (COD), surfactants, total coliforms, and thermotolerant coliforms. The system was run at two different filtration rates: 6 and 2 m^3/m^2/day. Statistical analyses showed no significant differences in the majority of the results when filtration rate changed from 6 to 2 m^3/m^2/day. The average removal efficiencies with regard to the turbidity, apparent color, COD and BOD were 61, 54, 56, and 56%, respectively, for the sand filter, and 66, 61, 60, and 51%, respectively, for the slate waste filter. Both systems showed good efficiencies in removing surfactants, around 70%, while the pH reached values of around 7.80. The average removal efficiencies of the total and thermotolerant coliforms were of 61 and 90%, respectively, for the sand filter, and 67 and 80%, respectively, for the slate waste filter. The statistical analysis found no significant differences between the responses of the two systems, which attest to the fact that the slate waste can be a substitute for sand. The maximum levels of efficiency were high, indicating the potential of the systems, and suggesting their optimization in order to achieve much higher average efficiencies.

1. Introduction

The growing pressure on the water resources needed to meet the demands of society can bring the supply system to its limits (Couto et al., 2015).

In addition, conflicting water uses contribute significantly to the increasing concerns about water availability. In this scenario, water conservation gains significant importance, since it involves controlled and efficient use, as well as wastewater reuse measures (Couto et al., 2015).

As a result of the increase in periods of drought, exacerbated in part by climate change and deforestation, as well as the changes in water consumption patterns, unconventional technologies for the conservation of this resource are gaining support. These alternatives can be implemented at different scales, either centralized or decentralized, with the decentralized scale becoming more interesting in the case of block systems, like hospitals, shopping centers, airports, schools (Libralato et al., 2012), and individual systems (i.e. single-family homes in rural or urban areas) (Mourad et al., 2011).

The use of local sources, such as rainwater and greywater, can help reduce dependence on large infrastructures, including dams and desalination transfer plants, thus improving the quality of freshwater ecosystems and reducing conflicts over water resources (Domènech et al., 2013).

In urban areas, residential, commercial, and public buildings are major consumers of water, generating a large quantity of wastewater. Therefore, the incorporation of sustainability practices in buildings is a growing trend in the market, since it provides many benefits to society, and in its social and economic environmental aspects (FIEMG, 2008; Proença and Ghisi, 2013).

Treated effluent has been considered to be a suitable alternative

* Corresponding author.
E-mail addresses: mariah.zipf@gmail.com (M.S. Zipf), ivonegp@furb.br (I.G. Pinheiro), mariana.conegero@gmail.com (M.G. Conegero).

http://dx.doi.org/10.1016/j.jenvman.2016.03.035
0301-4797/

source for water, and is already used in many dry regions around the world for non-potable water needs (Almeida et al., 2013). In this context, greywater reuse is one of the main options for reducing potable water consumption in households, commercial buildings, and industries (Couto et al., 2015).

Various technologies are being studied, like wetlands (Zhang et al., 2014; Saumya et al., 2015; Laaffat et al., 2015; Ramprasad and Philip, 2016), rotating biological contactors, membrane bioreactors with UV disinfection (Friedler and Gilboa, 2010), photooxidation over TiO_2 films (Lopez et al., 2015), electrochemical reactors (Vakil et al., 2014), and aerobic digestion with hydrogen peroxide disinfection (Teh et al., 2015), as treatment systems for wastewater separated at the source (such as greywater), and can be technically simpler, facilitating reuse (Couto et al., 2015).

Slow sand filtration has, historically, been a technological alternative in this sense; however, the filter media may aggregate a positive environmental impact when the sand is replaced by waste, providing a venue for waste recovery. Studies have also reported the use of organic wastes, like sugarcane bagasse, sawdust, rice hulls, and pine bark (Brandão et al., 2000, 2003; Lo Monaco et al., 2011; Dalahmeh et al., 2014), as filter media. Non-metallic mineral wastes, including rock extraction wastes, are also considered to be attractive.

The treated greywater can be used for non-potable purposes such toilet flushing, car washing and irrigation, in some cases (Barışçı and Turkay, 2016). In Brazil there is no specific legislation for greywater, but there is the Brazilian ABNT technical standard number 13969 (ABNT, 1997) which deals with treated sewage predicting its reuse, among others, in car washing, watering gardens, washing sidewalks, toilet flushing and irrigation of orchards. These uses are categorized into four classes, each one considering different parameters and limits. These parameters are pH, turbidity, coliform, total dissolved solids, dissolved oxygen and residual chlorine.

In this context, this study aimed to address unconventional water conservation measures applicable to residential, commercial, and public buildings, considering their greywater, in order to evaluate simplified treatment that may be viable both operationally and economically. Two simplified treatments with two stages each were studied: slow sand filtration followed by a granular activated carbon filter, and slow slate waste filtration followed by a granular activated carbon filter. These media were chosen because this study aims to contribute to the sustainability of buildings, not only with the proposal for a simplified system for greywater reuse, but also with an evaluation of slate waste being proposed. Slate is one of the rocks most commonly used in construction in Brazil, and slate waste is found in large quantities in the region.

2. Materials and methods

The experimental system consisted of a storage tank and two greywater treatment systems installed at Campus II of the Foundation Regional University of Blumenau (FURB) in the city of Blumenau, Santa Catarina, Brazil. The first system was composed of a slow sand filter followed by a granular activated carbon filter, and the second filter was slow slate waste, also followed by a granular activated carbon filter; in total, 4 filters were used.

This study was conducted using greywater *in natura*, with two filtration rates. Physicochemical and microbiological analyses of the raw and treated water were performed, which allowed the efficiencies of the systems to be evaluated and compared. For this research, the greywater was collected from 18 basins of both women's and men's toilets in a classroom block of FURB, which was conducted to a storage reservoir that also served as an equalization tank. The greywater was sent via gravity to the proposed treatment filter, at a constant flow rate controlled by a tap, with a bypass system diverting excess effluent into the sewage disposal system. Before reaching the reservoir, the greywater went through preliminary treatment composed of a screen with openings of approximately 1 mm, in order to retain the coarser solids.

2.1. Filter media characterization and cleaning

The sand was washed in a Tyler sieve (n. 14, openings of 1.18 mm) to remove the coarse grains, and then passed through a hydraulic separator in order to perform an additional washing, discarding the fine grains. The slate waste was passed through a mechanical sieving process, during which the fine grains were separated. Then, the dry samples of the sand, slate waste, and granular activated carbon were passed through a mechanical sieving procedure in order to determine their particle size distribution. Finally, the mean surface diameter (Ds), uniformity coefficient (Cu), and fineness modulus (FM) ($MF = \sum$% accumulated without the bottom/10) were determined.

Testing was carried out on a pilot scale to determine the intrinsic permeability of the filter media using Darcy's Law ($Q = K \times S \times \Delta P / u \times L$), where Q is the flow rate (m^3/s), K is the permeability (m^2), S corresponds to the cross-sectional area (m^2), ΔP is the pressure difference (Pa), L is the thickness of the filter layer (m), and μ is the dynamic viscosity (Ns/m^2).

2.2. Filter installation

The sand, slate waste, and two activated carbon filters were built on supports of rigid PVC pipes, with diameters of 0.2 m and heights of 1.60 m for the sand and slate waste filters, and heights of 1.40 m for the activated carbon filters. A cover of the same diameter and material was placed at the bottom of each base, which settled at the connections of the output tubes. At four centimeters from the bottom of each filter, an acrylic plate with circular orifices was placed in order to sustain the filter material. The PVC bases of the filters were filled with a 20 cm layer of crushed stone and 90 cm layer of the filter medium (one with sand and the other with slate waste), both surrounded by geotextile layers. The choice of 90 cm was based on the indications of the Brazilian ABNT technical standard number 12216 (ABNT, 1992). The granular activated carbon filters had thicknesses of 60 cm, over 10 cm layers of gravel support that were surrounded by geotextiles.

2.3. Systems operation and performance

First, the filters were filled with drinking water to regulate the piezometers and carry out a further cleaning of the layers; once the systems were stabilized, the greywater inlet was released. The systems worked at filtration rates of 6 and 2 m^3/m^2/day, corresponding to constant flow rates of 7.85 and 2.62 L/h, respectively, with a downward flow in all of the filters.

The Brazilian ABNT technical standard number 12216 (ABNT, 1992) suggests a maximum filtration rate for slow filter of 6 m^3/m^2/day. Values between 2 and 5 m^3/m^2/day have been recommended according to the variation on the quality of the effluent and the total available hydraulic head (Di Bernardo et al., 1999). Hence, based on these recommendations it was decided to use filtration rates of 6 and 2 m^3/m^2/day.

The monitoring of these systems was conducted over 28 weeks. During the first 8 weeks of ripening of the filters, the filtration rate was 6 m^3/m^2/day, and only pH, turbidity, apparent color and COD were monitored. After, the filters worked by 13 weeks with a filtration rate of 6 m^3/m^2/day and through the last 7 weeks with a rate of 2 m^3/m^2/day and the monitoring was performed through