Science of the Total Environment 551–552 (2016) 706–711

Contents lists available at ScienceDirect

Science of the Total Environment

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

Single house on-site grey water treatment using a submerged membrane bioreactor for toilet flushing

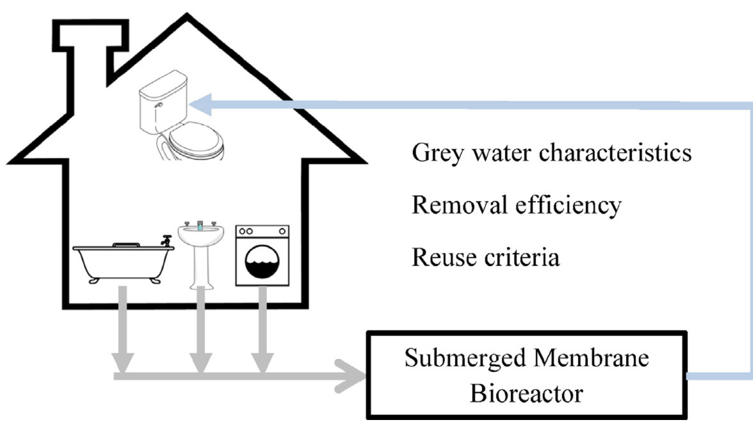
M.S. Fountoulakis *, N. Markakis, I. Petousi, T. Manios

Department of Agricultural Technology, Technological Educational Institute of Crete, Heraklion, Greece

HIGHLIGHTS

- Membrane bioreactor is an effective method for grey water treatment.
- Anionic surfactants removed at about 80%.
- Treated grey water is almost free of pathogenic content.
- Nitrogen content in the influent and the effluent varied seasonally.
- Effluent satisfy the international guidelines for indoor reuse.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 17 December 2015
Received in revised form 8 February 2016
Accepted 8 February 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Wastewater
Anionic surfactants
Removal efficiency
Regulations
Recycled water

ABSTRACT

Wastewater recycling has been and continues to be practiced all over the world for a variety of reasons including: increasing water availability, combating water shortages and drought, and supporting environmental and public health protection. Nowadays, one of the most interesting issues for wastewater recycling is the on-site treatment and reuse of grey water. During this study the efficiency of a compact Submerged Membrane Bioreactor (SMBR) system to treat real grey water in a single house in Crete, Greece, was examined. In the study, grey water was collected from a bathtub, shower and washing machine containing significant amounts of organic matter and pathogens. Chemical oxygen demand (COD) removal in the system was approximately 87%. Total suspended solids (TSS) were reduced from 95 mg L^{-1} in the influent to 8 mg L^{-1} in the effluent. The efficiency of the system to reduce anionic surfactants was about 80%. Fecal and total coliforms decreased significantly using the SMBR system due to rejection, by the membrane, used in the study. Overall, the SMBR treatment produces average effluent values that would satisfy international guidelines for indoor reuse applications such as toilet flushing.

1. Introduction

Wastewater recycling has been and continues to be practiced all over the world for a variety of reasons including: increasing water availability, combating water shortages and drought, and supporting

* Corresponding author.
E-mail address: mfountoul@staff.teicrete.gr (M.S. Fountoulakis).

http://dx.doi.org/10.1016/j.scitotenv.2016.02.057

environmental and public health protection (U.S. Environmental Protection Agency, 2004). Nowadays, one of the most interesting issues for wastewater recycling is the on-site treatment and reuse of grey water.

Grey water has been defined as wastewater originating from bathtubs, showers, hand basins, washing machines, dishwashers and kitchen sinks (Eriksson et al., 2009). Recently, a trend has emerged by which grey water is excluded from kitchen sinks and dishwashers (Oron et al., 2014). The advantage of recycling grey water is that it is a plentiful water source with a low pathogen and organic content. To illustrate, grey water represents 50–70% of total consumed water but contains only 30% of the organic fraction and 9–20% of the nutrients, thereby making it a good source for water reuse. Moreover, in an individual household, it has been established that grey water could potentially support the amount of water needed for toilet flushing and outdoor uses such as car washing and garden watering. Grey water varies regionally and over time. Water supply quality and activities in the house have an effect on the characteristics of grey water. Grey water originating from the bathroom and laundry includes mainly chemicals (detergents, soaps and salts) and several million pathogenic bacteria, which can cause a health hazard if this water is reused without proper treatment. Therefore, grey water must undergo certain treatments so that it can be made ready for reuse (Bani-Melhem et al., 2015).

Recently, the use of grey water has been encouraged by several countries worldwide including Australia (Pinto and Maheshwari, 2010), USA (Yu et al., 2013), Japan (Ogoshi et al., 2001), Jordan (Halalsheh et al., 2008), Cyprus (Charalambous et al., 2011) and Israel (Oron et al., 2014). Australia, for example, has already developed guidelines for grey water reuse and offers rebates for the installation of grey water systems. Severe droughts resulting in stringent restrictions on outdoor tap water use have resulted in up to 71% of Melbourne households (ABS, Australian Bureau of Statistics, 2007) reusing grey water most frequently collected from laundry use and bathroom. In Tokyo, Japan grey water recycling is mandatory for buildings with an area >30,000 m^2 or with a potential non-potable demand of more than 100 m^3 per day. The government has created incentives in this respect: In order to offset the costs associated with construction, the Japanese Ministry of Construction provides subsidies of up to 50% of the capital costs. Meanwhile, in Palo Alto, California, officials are promoting incentives that will help offset the high costs associated with the installation of advanced grey water treatment systems. City officials are offering homeowners $1.50 per square foot, up to $3000, of lawn removal if grey water irrigation and less water-demanding landscaping are established.

Depending on the required reuse applications, different treatment technologies including physical (March et al., 2004), chemical (Pidou et al., 2008; Lin et al., 2005) and biological (Eriksson et al., 2009; Leal et al., 2012; Lamine et al., 2007) operational methods can be implemented for grey water treatment. So while, sand filter or settlement and flotation are used for landscape irrigation, a more complex system is required, on the other hand, for an "in-house" reuse of treated grey water (Li et al., 2009). Rotary biological contactors (RBC) (Eriksson et al., 2009; Nolde, 1999), membrane bioreactors (Bani-Melhem et al., 2015; Huelgas and Funamizu, 2010; Lesjean and Gnirss, 2006), constructed wetlands (Kadewa et al., 2010; Comino et al., 2013) and sequencing batch reactors (SBR) (Gabarro et al., 2013; Krishnan et al., 2008) seem to be the more interesting treatment options for indoor reuse of grey water. Among the different treatment methods, the membrane bioreactor (MBR) appears to be an attractive method for grey water treatment, particularly in collective urban residential buildings since it combines physical separation of colloidal substances, including pathogenic bacteria, with aerobic biological treatment of dissolved organic matter, (Lazarova et al., 2003; Pidou, 2006; Li et al., 2009).

Although several previous studies have been conducted on grey water treatment using MBR technology (the sources of grey water and types of membrane used in these works are presented in Table 1), it is evident that there is a real lack of information on the behavior of MBR systems under real conditions in the case of single houses. Grey water from single households is a resource and can be reused on-site, if treated appropriately, for toilet flushing, car washing and laundry use. Substituting grey water for drinking water for these end uses will not only reduce the demand on drinking water supplies, but will also reduce the amount of wastewater discharged into the environment. When it comes to single houses, higher fluctuations in both quantity and quality characteristics of grey water are observed depending on the residents' habits which may have an effect on the performance of the MBR. During this study, the efficiency of a compact SMBR system in treating real grey water in a single house in Crete, Greece, was examined in which physical, chemical and microbial characteristics of the effluent were monitored and compared with the influent.

Table 1
Previous studies about greywater treatment with MBR.

Country	Water source	Building	Membrane type
UK[a]	Artificial	Multistory building	Flat
China[b]	Showers (mainly)	University building	Hollow
Germany[c]	Bathrooms & kitchens	Apartments & office	Flat
Morocco[d]	Showers	Sports & leisure club	Hollow
UK[e]	Showers & bathroom sinks	University building	Flat
Spain[f]	Showers & bathroom sinks	Company Building	Flat
Austria[g]	Artificial	Single house	Hollow
Jordan[h]	Cleaning and sinks	University building	Hollow

[a] Jefferson et al. (2000).
[b] Liu et al. (2005).
[c] Lesjean and Gnirss, 2006.
[d] Merz et al. (2007).
[e] Winward et al. (2008).
[f] Santasmasas et al. (2013).
[g] Jabornig and Favero (2013).
[h] Bani-Melhem et al. (2015).

2. Materials & methods

2.1. Experimental setup

The SMBR used in this study consisted of a bioreactor with a working volume of 1.0 m^3 which also included sufficient balancing volume for incoming grey water flushes and a flat plate membrane (SiClaro FM611, Martin) with a pore size of 0.04 μm and a total surface area of 6.25 m^2. Aeration was provided at the base of the membrane module via a diffuser supplied with air from an air compressor. The grey water flowed up to the SMBR system using the force of gravity. The water level in the SMBR was controlled by a pump and a float switch system. When the water level in the tank reached a high level (1.0 m^3), a float switch activated the suction pump and air compressor. On the other hand, when water level reached a low level (0.8 m^3), the suction pump and air compressor were turned off. In order to reduce the operating cost of the SMBR, aeration was applied only when the suction pump was turned on.

The treatment unit was also equipped with a UV lamp (AT 1500, Norwego) at 254 nm for additional disinfection and a flow meter to record the quantity of grey water. The UV lamp was inserted in-line with the treated effluent pipe. The UV dose at the maximum flow rate was 40 mW s/cm^2. The disinfection compartment was equipped with an internal current sensing circuit that continuously monitored the performance of the UV lamp.

The system was installed in a single house in Gournes, Crete, Greece, which is permanently inhabited by two people (father and mother) who often host their daughter. Grey water in the house was collected from a bathtub, a shower and a washing machine.