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Decentralized light greywater treatment using aerobic digestion and hydrogen peroxide disinfection for non-potable reuse

X.Y. Teh [a], P.E. Poh [a, b, *], D. Gouwanda [a], M.N. Chong [a, b]

[a] School of Engineering, Monash University Malaysia, Jalan Lagoon Selatan, 46150 Bandar Sunway, Selangor, Malaysia
[b] Sustainable Water Alliance, Advanced Engineering Platform, Monash University Malaysia, Jalan Lagoon Selatan, 46150 Bandar Sunway, Selangor, Malaysia

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ABSTRACT

Implementation of decentralized greywater treatment systems can potentially solve freshwater scarcity issue as greywater is generated in large amounts, and reuse of treated greywater could reduce the demand of freshwater. Nevertheless, greywater treatment systems are sophisticated, involving many units of process equipment. Hence, there is a need to develop greywater treatment systems that can be easily operated, maintained, low cost and does not compromise treated effluent quality. An aerobic digestion unit integrated with a hydrogen peroxide disinfection unit was evaluated in this study for the purpose of greywater treatment to the standard for non-potable usage. This system was successful in removing 88% and 68% of total suspended solids and chemical oxygen demand respectively, with optimal operation settings determined to be 5 h of hydraulic retention time and an organic loading rate of 2.16 gCOD/Lday. Disinfection with hydrogen peroxide at concentration of 1 mL/L removed approximately log CFU/100 mL of bacteria and all bacteria can be eradicated after 1 day of storage. The system evaluated in this study was found to be simpler in comparison to other treatment processes used. Though further optimization will be required maximize the treatment efficiency of this system, it has the potential for implementation in small communities due to minimal microbial activity after storage and relatively small area required for treatment.

1. Introduction

Freshwater scarcity is a serious issue that affects at least a fifth of the world's population (Jeswani and Azapagic, 2011; Shirazi and Kargari, 2013) and more will be affected due to population growth, mismanagement, increased urbanization and climate change. The issue of freshwater scarcity has led to intensified research in the treatment and reuse of domestic wastewater. Greywater, a fraction of domestic wastewater, represents the largest potential source of water conservation in domestic homes (Gulyas et al., 2009). It is commonly described as urban wastewater from bathrooms, laundry facilities, dishwashers and kitchen sinks (Hourlier et al., 2010). Greywater reuse within a household has been found to be able to supply sufficient water that will lead to 29–47% reduction in potable water consumption which is not only economically beneficial, but is also able to reduce the need for new supplies of fresh water (Hourlier et al., 2010; Al-Jayyousi, 2003). Treated greywater can be used for many purpose such as toilet flushing, gardening, washing of floor and outdoor areas etc. (Galvis et al., 2014).

The recent interest in greywater reuse has been directed to small-scale and on-site treatment where decentralized greywater treatment is carried out within the household, neighbourhood, or community (Al-Jayyousi, 2003). Naylor et al. (2012) have reported that greywater reuse systems have some significant disadvantages when compared to stormwater harvesting. This is mainly due to higher degree of sophistication of greywater treatment systems with greater amount of process equipment units. Therefore, there is a need to develop greywater treatment systems that are simple to operate and maintain, low cost and produce quality effluent

Abbreviations: APHA, American Public Health Association; COD, Chemical oxygen demand; HRT, Hydraulic retention time; LDPE, Low density polyethylene; OLR, Organic loading rate; POME, Palm oil mill effluent; TSS, Total suspended solid; UV, Ultraviolet; UVC, Ultraviolet C (germicidal ultraviolet); VSS, Volatile suspended solid.

* Corresponding author. School of Engineering, Monash University Malaysia, Jalan Lagoon Selatan, 46150 Bandar Sunway, Selangor, Malaysia. Tel.: +60 3 55146272; fax: +60 3 55146207.
E-mail address: poh.phaik.eong@monash.edu (P.E. Poh).

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consistently in order to encourage greywater reuse (Santos et al., 2012).

Researches were done to implement different treatment methods with the aim to produce treated greywater that is suitable for reuse. Some of the more recent works include the use of UVC/H_2O_2 (Chin et al., 2009), solar photocatalytic oxidation with powdered activated carbon (Gulyas et al., 2009), filtration and UV disinfection (Santos et al., 2012). Many of these methods were ineffective to treat greywater as a unit on its own and multiple process needs to be integrated to produce treated effluent to conform to useable standards (Li et al., 2009). Furthermore, some processes such as chlorine disinfection produces by-products that are potentially harmful to human beings. This concurs with the findings by Naylor et al. (2012) and thus, it is necessary to carefully select and evaluate the process equipment for greywater treatment to propose a decentralized treatment system that can be effectively implemented to reduce fresh water consumption.

In this article, an aerobic digestion unit was integrated with a H_2O_2 disinfection unit for the purpose of greywater treatment to the standard for non-potable usage. The effects of several operating parameters such as HRT, OLR and H_2O_2 concentration on the treatment efficiency was investigated to obtain an optimized system to produce quality effluent. The performance of this system was compared with others for process evaluation. The main criterion for technology selection in this study was geared towards cleaner production where the selected process produces least waste with high quality throughput. Besides that, no studies was conducted to integrate aerobic and hydrogen peroxide disinfection unit for greywater treatment. Aerobic digestion was selected as a primary treatment unit as aerobic systems were reported to be able to achieve excellent organic and turbidity removals (Li et al., 2009) and does not require any usage of chemicals. On the other hand, a hydrogen peroxide disinfection unit is incorporated after aerobic digestion to ensure that the treated effluent is safe for handling. H_2O_2 is deemed to be the most suitable disinfectant due to its strong capacity for disinfection, low cost, and does not leave any environmental footprint (Ronen et al., 2010).

2. Materials and methods

This section provides specifications of the materials used in this study and the approaches taken to evaluate the performance of the integrated aerobic and hydrogen disinfection unit.

2.1. Materials

Materials that were used in this study are COD digestion vials, high range (20–1500 mg/L) and low range (3–150 mg/L) (HACH, USA) for COD test; BOD nutrient buffer pillows and Nitrification inhibitor for BOD, Formula 2533™, TCMP (HACH, USA) for BOD test; hydrogen peroxide, 35% w/w (R&M chemicals, UK) as the disinfectant in the experimental runs and Brilliance™ *Escherichia coli*/coliform selective medium, CM1046 by Oxoid (UK) for detection and enumeration of *E. coli* and other coliforms. These chemicals were used as received without further processing.

2.2. Light greywater

Samples of light greywater were collected daily from showers and drains of bathroom sinks of a typical urban home occupied by four people located in Selangor, Malaysia. As there was no access to outflow pipes from the bathroom, each family member had to fill a 5 L LDPE flask with greywater obtained from showers in order to collect the samples. The composite samples were transported under dark conditions for treatment and analysis. These samples were then preserved in a refrigerator at 4 ± 2 °C if not used immediately. Characteristics of the sampled greywater are listed in Table 1.

2.3. Seed sludge

The seed sludge for this study was previously used for POME treatment. Prior to its usage, the seed sludge was acclimatized to new environmental conditions by aerating it with the light greywater so that it can adapt to the specific characteristics of greywater. The sludge was considered acclimatized when it removed at least 60% of COD from the light greywater. The acclimatized seed sludge has a dark brown colour appearance with a slight earthy odour, consisting of mainly fine particles with a VSS value of approximately 2000 mg/L.

2.4. Experimental set-up

The experimental rig consists of 4 stainless steel tanks: feed greywater tank, hydrogen peroxide storage tank, aeration tank, and disinfection tank. The schematic of the experimental rig is shown in Fig. 1. The aeration tank has a volume of 9 L and a working volume of 7.9 L. Mechanical aeration in the tank is achieved by pumping air continuously through the bottom of the tank, which is connected to a mini air compressor. The disinfection tank has a total volume of 50 L, of which only 20 L of working volume is used during normal operation. Experiments were carried out at ambient temperature of approximately 25 °C.

2.5. Start-up and experimental runs

The feed greywater tank was initially filled with 50 L of light greywater. 800 mL of acclimatized seed sludge was then added to the aeration tank, filling up about 10% of the total working volume and the remaining volume of the tank was filled with light greywater. The system was then operated with an initial feed flow rate of about 0.7 ml/s. This flow rate was selected so that HRT of greywater in the aeration tank is not too short to cause excessive washout of viable biomass and also not too long to be detrimental to sludge granulation. After 2 weeks of continuous operation at constant flow rate, COD removal of the system was consistent at 60–70%, indicating that the system start-up was complete.

After the start-up period, 17 experiment runs (as shown in Table 2) were performed by varying HRT, feed COD and hydrogen peroxide concentrations to monitor the system's treatment efficiency. The effect of HRT on the treatment system was firstly investigated by varying HRT from 1 to 6 h at fixed feed COD and hydrogen peroxide concentrations. HRT was the first criteria for evaluation as this parameter influences the sizing of the treatment systems, where long HRTs implies larger tank volume to allow for sufficient contact time of the wastewater in the treatment system.

Table 1
Light greywater characteristics.

	Minimum	Maximum	Average	Standard deviation
pH	5.94	6.4	6.13	0.12
Suspended solids (TSS) (mg/L)	36	224	81	53.92
Chemical oxygen demand (COD) (mg/L)	146	903	445	221.13
Biochemical oxygen demand (BOD_5) (mg/L)	168	673	349	184.51
E. coli (CFU/100 mL)	0	5.2×10^6	4.5×10^5	1.5×10^6
Total coliforms (CFU/100 mL)	6.04×10^7	1.91×10^8	1.10×10^8	3.83×10^7
Other microorganisms (CFU/100 mL)	4.40×10^7	1.75×10^8	1.07×10^8	3.68×10^7