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Optimizing the in-line ozone injection and delivery strategy in a multistage pilot-scale greywater treatment system: System validation and cost-benefit analysis

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ABSTRACT

Greywater is a potential source of recycled water for household that has often been overlooked. Although greywater is lightly contaminated, a holistic treatment and disinfection system of greywater is still warranted to ensure public health issues associated with the cross-connection of third pipe reticulation in household are minimized. This study assessed on the treatment performance of a commercial pilot-scale greywater treatment system comprising of a multi-medium sand filter, granulated activated carbon (GAC) filter and an ozonation disinfection system. The operational volume flow rate (10–20 L/min) and ozone dosing rate (5–20 g/h) for maximum removal of contaminants in greywater were investigated. This study found that the increase in operational volume flow rate decreased the overall performance of the greywater treatment and disinfection system. The optimum operating volume flow rate was found to be 10 L/min, removing 72.6% of chemical oxygen demand (COD) and 42.9% (0.85-log removal) of *Escherichia coli* without recirculation. Recirculation of greywater was introduced to the ozonation disinfection system in order to improve the disinfection efficiency. It was found that all bacteria present in the treated greywater effluent were completely disinfected with a recirculation period of 1 h.

Introduction

Greywater is a source of wastewater generated from showers, hand wash basin, laundry or preparation of food in the kitchen [1]. It is consistently generated daily and contains low concentrations of organic compounds and pathogens when compared to domestic wastewater with sewage inputs. Therefore, greywater has a huge potential to be treated, recycled and reused, especially when the availability of freshwater is a concern in many arid countries. Treated greywater effluent can be reused for irrigation, car washing and toilet flushing to augment the availability of drinking water for other potable fit-for-purpose applications.

Though greywater is lightly contaminated, there is still a need for treatment before reuse as the microorganism content in the treated greywater effluent could potentially cause public health issues through close human contact [2]. Greywater effluent that is deemed safe for reuse can normally be obtained through several treatment barriers, which include: (i) pre-treatment for the removal of coarse materials; (ii) primary and secondary treatments to remove majority of the contaminants and (iii) tertiary disinfection treatment to ensure the effluent is microbiologically safe for handling.

To date, different processes have been used for the treatment and disinfection of greywater effluent. Some popular examples of the primary greywater treatment systems are chemical processes, biological processes and physical and physicochemical processes [3–6]. In general, these systems are operated to reduce solids,

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Table 1
Greywater characteristic for this study.

Parameters	Concentration (mg/L)[a]
pH	6.20–7.66
Turbidity	6.2–48.4
Total suspended solids (TSS)	42.6–63.3
Chemical oxygen demand (COD)	63.5–153.0
Biochemical oxygen demand (BOD_5)	45.6–58.5
Escherichia coli (*E. coli*)	0–17,900 cfu/mL
Pathogenic bacteria	0–3400 cfu/mL
Other coliforms	0–2650 cfu/mL

[a] All units are in mg/L unless specified and pH which has no units.

organic and inorganic contaminants in greywater source. On the other hand, chlorination, ultraviolet (UV), hydrogen peroxide, ozonation, advanced oxidation are the typical disinfection methods used for greywater [7,8] to ensure that the treated effluent is microbiologically safe for reuse.

Most previous studies on the treatment of greywater for reuse purpose were carried out in laboratory-scale systems, mainly for understanding the principles of the treatment systems as well as to evaluate the effectiveness of individual units of primary, secondary or tertiary disinfection treatment systems [9–13]. To date, there are limited references available in the open literatures on the treatment of greywater in pilot- or large-scale commercial systems that encompass different stages of treatment. Thus, it is necessary to evaluate the multi-stage treatment and disinfection system as a whole in a pilot- or large-scale commercial system. This is to enable the identification of treatment limitation of a complete and integrated greywater treatment system and assess the suitable operating conditions, providing insight to urban developers on the adequacy of such system for implementation in new greenfield or retrofitted brownfield developments.

Thus, the main aim of this study was to assess the treatment performance of a commercial pilot-scale greywater treatment system comprising of a multi-medium (sand) filter, activated carbon filter and an ozone disinfection system. Conventionally, ozone disinfection is conducted for treated effluent retained in a tank, where ozone is in contact with the effluent for a fixed period of time. This study examined the use of an in-line ozone disinfection system to eliminate the requirement of an additional disinfection tank, thus reducing the physical footprint and overall cost of the pilot-scale system. This study also evaluated the cost-benefit analysis of having an installed greywater treatment system for recycling purpose against the typical Malaysian households with only the conventional dual-reticulation water system.

Materials and methods

Greywater

Bathwater from a group of workers in a factory located in the coordinate (3.0692105, 101.5965965) was collected in a polyvinyl chloride (PVC) tank and transported to Monash University Malaysia for treatment on a weekly basis. The characteristics of the collected greywater are as listed in Table 1.

Pilot-scale greywater treatment system

Fig. 1 shows the schematic of the pilot-scale greywater treatment system that was used in this study. The pilot-scale system has a 1.3 m^3 PVC feed water tank, which is connected to a multi-medium filter with a stainless steel housing and dimension of 19.05 × 145 cm (D × H) (ER-19M, BACFREE), followed by a granular activated carbon (GAC) filter (BACFREE), which has similar capacity as the ER-19M and an ozone generator (CTO-20, Corona Discharge Ozone Generator). The treated greywater effluent after disinfection was stored in another 1.3 m^3 PVC water holding tank (clean water tank).

This pilot-scale greywater treatment system was also fitted with two centrifugal pumps to facilitate the transfer of greywater source to the treatment system, as well as for the recirculation of treated greywater effluent to the ozone injector. The system was also fitted with several sampling valves along the treatment process to allow sampling of treated greywater effluent at different stages of the greywater treatment system.

Evaluating the performance of pilot greywater treatment system

The pilot-scale greywater treatment system was operated in two different conditions in order to evaluate the performance of the system and to determine the optimum operating condition: (i) without recirculation of treated greywater; (ii) with recirculation of treated greywater. In the first condition, disinfected greywater effluent was directly stored in the clean water holding tank

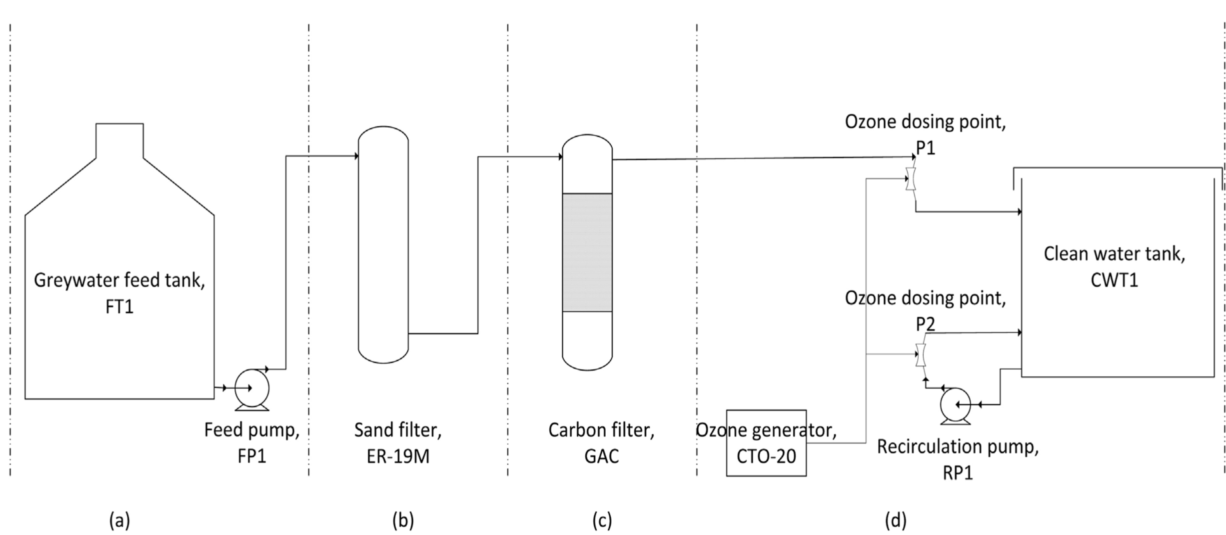

Fig. 1. Schematic diagram of the pilot-scale greywater treatment system; (a) greywater feed tank; (b) multi-medium sand filtration unit; (c) GAC column; (d) ozonation disinfection; (e) recirculation loop with ozonation.