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DESIGN OF GREY WATER TREATMENT SYSTEM FOR POLLUTION LOADING REDUCTION IN MALAYSIA

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Abstract

Population growth, rapid urbanization, higher standards of living and climate change have led to continuous growth of urban water consumption. International Water Management Institute (2002) projected that total urban water consumption will increase from 1995 to 2025 by 62%. Grey-water is considered to be almost 50 to 75 percent of whole domestic wastewater therefore it is vital to control the discharge of grey-water into the river. Grey water recycling practices must guard against risks to public health, safety, and the environment. The study proposes a compact design of a water treatment system to treat residential grey water in Malaysia. The proposed method adopts the idea of combining three basic treatment processes, namely, aeration, disinfection and filtration, in a compact reactor with the intention of reducing the operational cost, space and equipment. Aeration is important to promote pollutant degradation by aerobic microorganisms, while disinfection (UV) is imperative to eliminate pathogenic bacteria. Membrane filtration plays the role to remove suspended and dissolved pollutants of which are relatively smaller in size. The results have proven that the proposed system is effective in improving the quality of grey water, in which the parameters (BOD, COD, pH, turbidity, TSS, total P, total N, E. Coli) are maintained within the standard limits. Notably, this study is conducted in a laboratory environment and the good agreement between the results and the standards suggests that the proposed system is worth to be further developed for commercial use in future.

Keywords: Aeration; disinfection; grey water; Malaysia; membrane filtration;

1. INTRODUCTION

Global water resources are undergoing gradual depletion primarily due to pollution and according to a report from the United Nations, 2.7 billion citizens will be encountering water shortage problems by the year 2025. Consequently, several nations have been exploring various alternatives to address this major issue. One of the most practical and effective solutions is the development and implementation of grey water treatment systems to treat grey water, which is normally discharged from kitchen sinks, bathroom sinks, showers and/or baths, and laundry. Generally, grey water composes 50-70% of the total domestic wastewater [1]. Grey water has been the primary alternative water source on account of its relatively low organic pollutant content (30%) and high nutrient content (9-20%) as well as the source is relatively abundant as compared to the others [2]. These suggest that the treatment would be relatively simple and practical.

The treatment of grey water is performed via a series of steps, namely, pre-treatment, physical and/or biological and/or chemical treatments as well as disinfection [3]. Grey water initially undergoes pre-treatment to remove sediments and coarse particles. Subsequently, it is then channelled into the main treatment unit for further treatments. In the main treatment unit, physical or/and biological or/and chemical treatments are taken place. Physical treatment involves filtration and sedimentation to remove suspended solids and coarse particles, while biological treatment involves biological decomposition of organic pollutants by microorganisms as well as chemical treatment involves the addition of chemicals to stimulate flocculation and coagulation of pollutants, which consequently promote sedimentation. Finally, disinfection is performed to eliminate pathogenic bacteria via the use of UV [4] or the addition of chlorine [5].

As compared to other developed countries, the implementation of grey water treatment systems is relatively less common in Malaysia due to the limited resources and knowledge in executing and sustaining the systems. In Malaysia, grey water is normally treated together with black water in a centralized treatment facility

[6]. This centralized treatment system in Malaysia involves four main stages [7]. The wastewater will initially undergo pre-treatment to eliminate coarse substances before entering the primary treatment unit. The effluent will then be transferred from the primary treatment unit to the secondary treatment unit, such as activated sludge systems, sequencing batch reactors (SBRs), contact stabilization and rotating biological contactors (RBCs) before discharging into the water channels. Nevertheless, these treatment processes were found to be relatively complex, expensive and very sensitive to the changes in the environment. In addition, the low nutrient content in grey water would limit the treatment efficiency of a biological treatment system. The last treatment step, disinfection is needed to get rid of both the pathogens and odours from the treated grey water to preserve its hygiene and cleanliness. A few studies have been conducted in investigating and implementing grey water treatment systems in Malaysia. Mah, et al. [6] presented the conceptual modelling of a grey water treatment system, in which a pilot project, Ecological Sanitation (Ecosan) was proposed and its mathematical model was developed via simulation in Kuching, Sarawak in 2003. The target of the treatment system is to treat grey water generated from the kitchen, showers and washing machines, while the aim of this project is to reduce pollution caused by the discharge of untreated grey water into water streams. In this regard, the Ecosan project adopts the application of wetlands with integrated aerobic filter for grey water treatment. Consequently, the pollutant content released into the water channels is reduced. This treated grey water is suitable for non-potable reuse and a predicted average reduction of 40% of potable water consumption could be achieved. Furthermore, Oh, et al. [8] proposed a grey water recycling system with maximum capacity of 14.4 m^3/d, which is located at Monash University Malaysia. The recycling system is composed of a sand filter, an activated carbon filter and an ozone disinfection unit. The ozone dosage of the system was optimized to achieve the tip-top disinfection efficiency and thus, producing treated grey water that meets the non-potable reuse standards. Importantly, this system has been proven capable of saving fresh water or potable water, which could cater for 140 persons or 28 families with an average of 5 family members. Apart from that, Radin Mohamed, et al. [9] developed an ablution grey water recycling system in two mosques located at Batu Pahat, Johor. Ablution grey water has low pollutant content and it is usually treated with a simple sand-gravel filter. The treated grey water could be used for toilet flushing or garden watering.

The aforementioned literature demonstrates that the implementation of grey water systems in Malaysia is still infantile due various factors, e.g., limited resources and knowledge, etc. Even the use of grey water systems is growing in Malaysia, the systems involve separate steps of treatment, i.e., aeration and disinfection and filtration, which might incur more operational cost, space and equipment. Therefore, the present paper proposes a new different grey water treatment system, which combines the three main treatment steps in a compact reactor to treat residential grey water in Malaysia. In this regard, residential grey water refers to that is generated from residential household, e.g., bathing, toilet flushing, laundry, dishwashing, etc.

2. MATERIALS AND METHODS

2.1 Grey water treatment design

The proposed grey water treatment system consists of a bag-cartridge filter, a compact reactor (main tank) and several pumps, as shown in Figure 1. Generally, it comprises two main stages, in which, stage 1 involves the bag-cartridge filtration, and stage 2 involves the treatment of the compact reactor. The compact reactor is composed of a membrane filter, UV lamps and aeration bubble diffusers. The reactor is supported by the bag-cartridge filter to prevent or reduce the entry of large suspended particles into the tank. Initially, grey water flows into the bag-cartridge filter before entering the main tank. The treatment tank is designed such that the flow of grey water is guided from the edges to the centre of the tank. A square spiral liquid flow way is designed in the main tank, where, UV lamps are placed at the corners along the flow way and aeration bubble diffusers are located at the bottom of the main tank along the flow way. The primary objective of this spiral-shaped design is to optimize the rate of aeration and disinfection of grey water before undergoing membrane filtration. As the grey water enters the tank, aerobic microbial degradation and UV disinfection will occur concurrently and eventually, membrane filtration will take place. Aeration is needed to increase the amount of dissolved oxygen, which favours aerobic microbial growth and thereby promotes the degradation of organic pollutants. Disinfection is needed to eliminate pathogenic bacteria, while membrane filtration is needed to further remove suspended and dissolved pollutants. The specifications of the materials and equipment involved in operating the proposed system are listed in Table 1. Notably, a cellulose nitrate membrane with pore size of 0.45μm is adopted for membrane filtration in the present study. The performances of the system are subsequently investigated on the basis of the treated grey water quality by varying the conditions used, the configuration and operating parameters. Based on the results, the variables of the system are optimized to achieve tip top system efficiency as well as to meet the standard requirements.

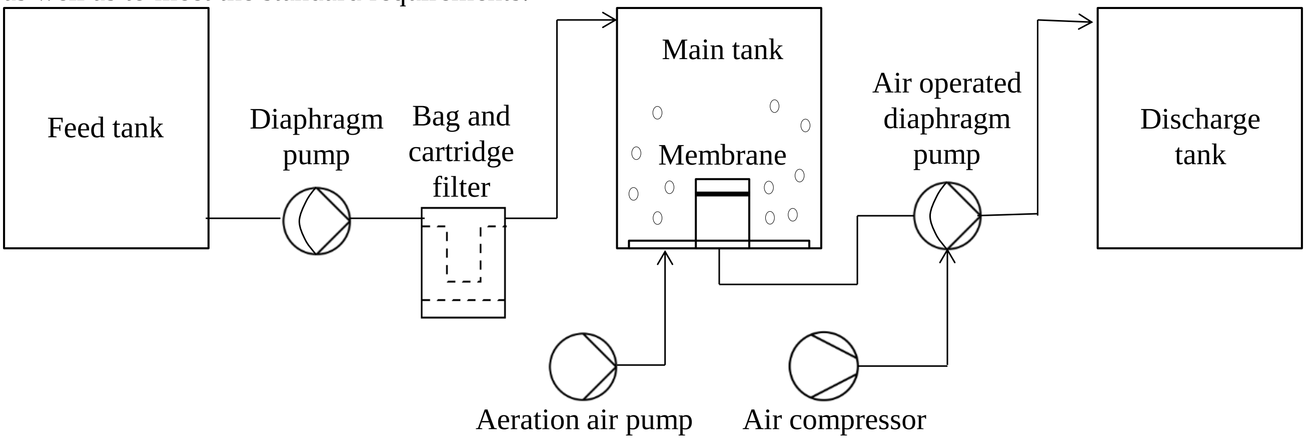

Figure 1. Schematic diagram of the proposed system

Table 1. Specifications of materials and equipment

Main tank	Dimension 50 x 50 x 50 cm^3
Bag and cartridge filter	5μm
UV lamps	SUV70D 50W 0.8A
Membrane	11306 Cellulose Nitrate 0.45μm 130mm thickness
Influent pump	Dauer HF-8367 DC 24V 125Psi (0.862MPa) 1.2L/min
Aeration air pump	Atman HP-4000 AC 220-240V/ 50Hz 20W 0.022MPa 35L/min
Air operated diaphragm pump	Wilden P.025 Plastic PTFE-Fitted Discharge pressure: 4Bar (0.4MPa)
Air compressor	LW-2501 2.5HP 2kW 116Psi (0.800 MPa) 120L/Min
DR900 multi-parameter portable colorimeter	Chemical oxygen demand (COD), total organic carbon (TOC), ammonium, nitride, nitrate, total nitrogen (Total N), orthophosphate, total phosphorus (Total P)
YSI ProDSS multi-parameter water quality meter	Dissolved oxygen (DO), pH, turbidity, total suspended solids (TSS), total dissolved solids (TDS)

2.2 Water sampling

The Penchala River is one of the main rivers in Klang that flows across urban areas where diverse land use is established. According to the recent water quality data, the Penchala River has been severely polluted and its water quality index (WQI) is reported to be in the range of III to V due to its catchment areas are mostly located at urban areas, where residential, commercial and industrial activities are prevalent. In this study, a sampling site, S1, which is located at high density residential areas, was selected and the exact location is shown in Figure 2.

Figure 2. Sampling site located at Jalan 19/21 (3° 7'33.22"N, 101°37'41.77"E).

Samples were collected at different time (morning, afternoon and night). In this study, a total of 15 samples were collected at the selected sampling site, in which, a total of 5 sampling days were spent and 3 samples were collected each day. Samples were collected from the drainage outlet and sent to laboratory for analyses. The sampling was done exactly at the point of discharge before flowing into the river. The water quality parameters of the samples (DO, pH, turbidity, TSS and TDS) were measured in-situ using the YSI ProDSS multi-parameter water quality meter. Biochemical oxygen demand (BOD_5) was calculated by quantifying the dissolved oxygen of the sample before and after the 5-day incubation at 200°C. In addition, total coliforms and E.Coli were measured by using the most probable number (MPN) method. The rest of parameters (COD, TOC, ammonium, nitride, nitrate, total N, orthophosphate and total P) were measured using the DR900 multi-parameter portable colorimeter.

3. RESULTS AND DISCUSSIONS

The proposed grey water treatment system comprises two main stages, in which, stage 1 involves the bag-cartridge filtration, and stage 2 involves the integration of aeration, disinfection and membrane filtration. Table 2 demonstrates the average values of 16 parameters of the grey water before and after treatment. Basically, BOD refers to the amount of dissolved oxygen needed by aerobic microorganisms to decompose organic pollutants, while COD refers to the amount of dissolved oxygen needed for the oxidation of all oxidizable substances in water. Due to its more complete measurement, the value of COD is usually higher than that of BOD. After treatment, both the BOD and COD are reduced by 48.53% and 36.90%, respectively. The increase in DO as well as decrease in both BOD and COD after treatment imply that aeration is important in favouring the degradation of organic pollutants by aerobic microorganisms as well as the oxidation of other substances. Furthermore, the pH of treated grey water is increased due to the presence of carbonates, which are formed via the dissolution of pollutant degradation by-products, such as carbon dioxide, in grey water. Apart from that, the turbidity, TSS and TDS also demonstrate significant reductions after treatment by 96.98%, 96.90% and 36.42%, respectively. These reductions suggest that the membrane filtration plays a substantial role in removing suspended and dissolved solids, which consequently reducing the turbidity of grey water. Besides, the content of nutrients (i.e. ammonium, nitrite, nitrate, orthophosphate, etc.) in grey water is also decreased discernibly up to 95.00% mainly due to the use of aeration, which is one of the effective ways for nutrient removal [10]. Removal of nutrients including dissolved nitrogen and phosphorus is one of the crucial steps of treatment to avoid eutrophication, which stimulates the growth of unwanted plants, such as algae and aquatic macrophytes. Resultantly, these unwanted plants will consume more oxygen and thus inhibit microbial degradation. In addition, nitrogen compounds are reported to be toxic to aquatic organisms and excessive nitrate concentrations in water (above 45 g/m^3) will as well lead to methemoglobinemia (which is a type of blood disorder where too little oxygen is delivered to cells). Therefore, aeration is needed to provide a sufficient amount of dissolved oxygen, which will indirectly reduce or remove nutrients in water via oxidation and reduction processes [10]. Total N is a measure of the sum of nitrite, nitrate and ammonium compounds in water, while total P is a measure of the sum of all phosphorus compounds in water. Similarly, significant reductions can be observed in both the total N and total P after treatment. The most common tests for bacterial contamination in water include the tests for total coliform and Escherichia coli (E. Coli). Total coliforms refer to bacteria that are abundant in human or animal wastes as well as in soil and surface water, while E. Coli bacteria refer to those that are specifically found in human and animal wastes. These bacteria are mostly pathogenic and the presence of a certain amount of these bacteria in water can be detrimental to human health and safety. In the present study, the counts of E. Coli and total coliforms are removed dramatically by 99.99% and 99.98%, respectively after treatment. The effective removal of these bacteria is mainly contributed by the use of UV rays for disinfection as well as the use of membrane filtration. UV disinfection is adopted instead of chlorine-based disinfection mainly to avoid the possible formation of by-products (in chlorine-based disinfection) that may be carcinogenic and may affect the treatment effectiveness.

Table 2. Grey water quality before and after treatment

No.	Parameters	Before	After	R (%)
1.	BOD mg/l	13.60	7.00	48.53
2.	COD mg/l	62.33	39.33	36.90
3.	TOC mg/l	18.20	10.10	44.51
4.	DO mg/l	1.26	9.46	-650.79
5.	PH	7.52	8.12	-7.98
6.	Turbidity NTU	159.46	4.81	96.98
7.	TSS mg/l	258.00	8.00	96.90
8.	TDS mg/l	346.00	220.00	36.42
9.	Ammonium mg/l	1.80	0.09	95.00
10.	Nitrite mg/l	0.07	0.01	85.71
11.	Nitrate mg/l	0.34	0.03	91.18
12.	Total N mg/l	15.60	2.10	86.54
13.	Orthophosphate mg/l	2.54	0.86	66.14
14.	Total Phosphorus mg/l	3.25	2.43	25.23
15.	Escherichia Coli MPN/100ml	1.26E+05	15.90	99.99
16.	Total coliforms MPN/100ml	1.60E+05	39	99.98

According to Oh, et al. [11], Malaysia does not have water quality standards for treated grey water, hence urban reuse guidelines are proposed on the basis of those implemented by other countries, i.e., USA, UK, Canada, Italy, Australia, New South Wales and Israel, as shown in Table 3 and Figure 3. After treatment, the BOD and COD are reduced and maintained below the standard limits. These imply that aeration plays an important role in the proposed system to promote microbial degradation with the provision of a sufficient amount of oxygen. Furthermore, the treated grey water is reported to be slightly alkaline with the pH maintained within the standard range as well as the turbidity and TSS also show good agreement with respect to the standards. These compliances clearly acknowledge the effectiveness of the membrane filtration in the proposed system. Besides, the total N is reduced and maintained below the standard limit after treatment. On the contrary, the total P is found exceeded the standard limit slightly. Despite, it is still acceptable as the treated grey water is designated for other reuse purposes other than drinking. While most of the available tests for E. Coli are measured in CFU/100ml, the test used in the present study is measured in MPN/100ml. After treatment, the count of E. Coli is reduced to 15.90 MPN/100ml, which is slightly higher than the allowable standard limit (10 CFU/100ml). According to Cho, et al. [12] as well as Gronewold and Wolpert [13], the E. Coli measured in MPN/100ml is usually higher than that measured in CFU/100ml. Therefore, it can be deduced that the count of E. Coli in the treated grey water is reasonable and acceptable. Overall, the proposed system is proven to be feasible in improving the quality of grey water for reuse purposes by removing the pollutants to certain limits.

Table 3. Standard guidelines implemented by other countries

No.	Parameters	Treated	Standards
1.	BOD mg/l	7.00	<20
2.	COD mg/l	39.33	<100
3.	PH	8.12	5-9.5
4.	Turbidity NTU	4.81	<10
5.	TSS mg/l	8.00	<30
6.	Total N mg/l	2.10	<15
7.	Total P mg/l	2.43	<2
8.	E. Coli MPN/100ml or CFU/100ml	15.90	<10

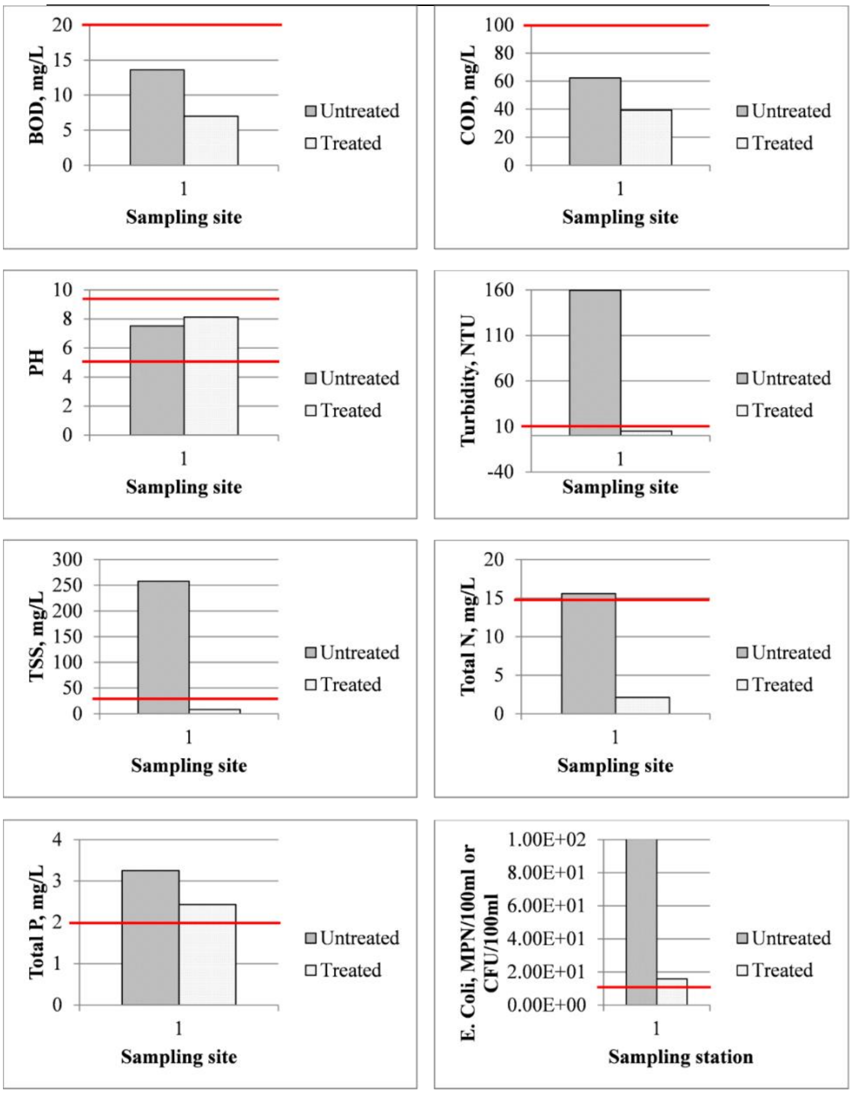

Figure 3. Selected parameters of grey water before and after treatment. Red horizontal line indicates the maximum standard limits.

4. CONCLUSION

A new different grey water treatment system has been designed to treat residential grey water in Malaysia. In the present paper, the technical design and efficiency of the system are the emphasis. The salient feature of the proposed system consists in the integration of aeration, disinfection and membrane filtration in a compact reactor, unlike those existing systems that involve separate treatment stages. Aeration is performed to promote degradation of organic pollutants by aerobic microorganisms and in the meantime, disinfection is carried out in the presence of UV light rays to get rid of pathogenic bacteria. Finally, membrane filtration is used to eliminate suspended and dissolved pollutants. By combining these three processes, the operational cost, space and equipment can be reduced considerably. The results have proven that the proposed system is effective in improving the quality of grey water (BOD, COD, TOC, DO, PH, turbidity, TSS, TDS, ammonium, nitrite, nitrate, total N, orthophosphate, total P, E. coli and total coliforms) under the condition that maintenance (e.g., cleaning of filters) should be performed frequently to avoid performance deterioration. It is notable that the present research involves an elementary laboratory-scale study of a new grey water treatment system, which is worth to be investigated and applied commercially in future.

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