Greywater Reclamation Using Recycled Vertical Subsurface-Flow Constructed Wetland (RVFCW) for Non Potable Usage

Azianabiha A. Halip @ Khalid, Siti Nurulhuda Mohd Imran and Shahrul Azwan Shakrani

Abstract Nowadays, the usage of a greywater as additional water resources options is increasing due to decline of water quantity available worldwide. The growing of recycled greywater for non potable purpose have been widely used around the world not only by water-scarce and dry regions countries such as in the Middle East and North Africa but also intensively applied by densely populated European countries such as England and Germany. Typically, about 100–200 L of greywater are being produced per person each day which represent the largest portion of domestic wastewater. Due to this soaring volume of greywater generated, it provides high potential for water conservation in household source. Nevertheless, greywater is always contaminated and required pre-treatment.The aim of this study was to study the potential and removal pollutant of RVFCW in greywater treatment. Four samples of greywater from two different sources were treated using RVFCW and the water quality parameters were tested after 4, 24 and 48 h. The results show that RVFCW has a potential in greywater treatment and able to remove more than 80 % of water parameters such as TSS, COD and turbidity. Thus, this study concluded that the RVFCW is capable as alternative treatment system for non-potable greywater reuse.

Keywords Greywater · Vertical flow constructed wetland · Wastewater reuse · Wastewater recycling · Alternative water source

A. A. Halip @ Khalid (✉) · S. N. M. Imran · S. A. Shakrani
Faculty of Civil Engineering, Universiti Teknologi Mara (UiTM), Shah Alam, Selangor, Malaysia
e-mail: azianabiha@gmail.com

R. Hassan et al. (eds.), *InCIEC 2013*, DOI: 10.1007/978-981-4585-02-6_67,

1 Introduction

In Malaysia, the water shortage and water scarcity is not a major the problem. With high number of rainfall distribution, the quantity of water resources available is enough for the long term period usage and the water crisis is rarely occurs. However, uncontrolled water usage can leads to wastage and could affect the sustainability of water supply in the future. In order to ensure that the water is used efficiently, the recycling of greywater for non potable purpose is one of the options. Greywater is usually defined as all of the wastewater produced in a household except toilets waste which known as a blackwater [1]. Yet, the raw greywater is often contaminated and possible presence of harmful microorganism. Moreover, without careful handling it will cause water logging, smell, and released of chemicals and anthropogenic elements [2, 3]. Pollutants such as metals that originated from rusty pipes and other chemicals content in household products such as detergents and preservatives can cause environmental harm when accumulated in the soil thus affecting plants and other microorganisms in the soil. It might also pose various health problem occurred primarily through direct contact with human body. In most countries, regulations or specific guidelines for greywater reuse are not available or are insufficient, hence used without any significant pre-treatment and a practice mistakenly considered safe [4]. The aim of this study were to assess the potential of RVFCW in greywater treatment based on removal capacity of selected pollutants.

2 Materials and Methods

2.1 Materials

The RVFCW method proposed is a modification technique that was described in [4]. Figure 1 presents schematic layout of RVFCW. The RVFCW consists of upper tank (wetland plant and media) (76 × 18 × 45 cm) and lower tank (treated sample) (76 × 18 × 45 cm). In this study, the media used consists of a 10 cm layer of sand, followed by a 10 cm layer of gravel with 5–10 mm diameter and a 10 cm layer of limestone pebbles with 5–10 mm diameter at the surface. For the purpose of this greywater treatment, a species of wetland plant called *Eichhornia Crassipes* (water hyacinth) has been chosen due to its high nutrient assimilative capacity and ability to filter suspended materials.

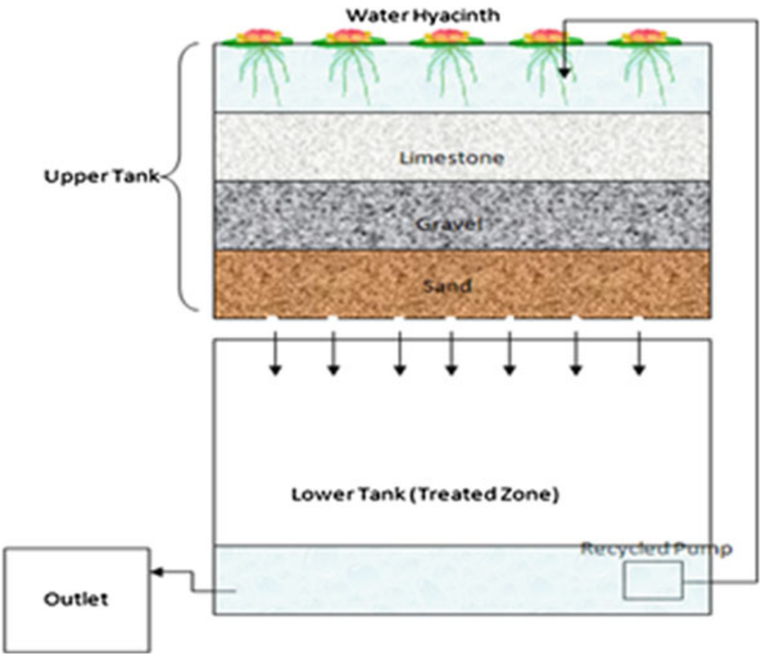

Fig. 1 Schematic diagram for RVFCW layout

2.2 Methods

The RVFCW system was constructed using two plastic aquarium tank with an upper tank was placed over a lower container. Holes were punctured at even intervals in the bottom of the upper tank. This was to allow water from the top to flow into the bottom tank. There is a plumbing pipes design to support an upper tank together with bottom tank.

When the greywater was introduced to the system, the greywater was percolated through the upper layer which consists of wetland plant; *E. crassipes* (water hyacinth) and three types of media. Then, it infiltrated from bottom layer of upper tank through the holes to the lower tank which acts as treated tank. The water pump was introduced to recycle the water back to upper tank through the perforated pipe. The process was continued until the time required for study the treated samples.

At the beginning of the study, the pore volume of the filter section and treated water reservoir was emptied and 20 L of raw greywater was introduced. For this study, raw greywater samples were collected from effluent in two different locations in UiTM Shah Alam. There were at Dataran Cendekia Cafeteria sump and Teratai College sump. A subsample of raw water was collected for analysis (time zero) of water quality parameters. Then, the samples of treated greywater were taken immediately after passed bed on period of 4, 24 and 48 h. It then was

Table 1 Removal percentage for different water parameters using RVFCW system

Parameters	Average removal (%)
pH	±10
Conductivity	0
TSS	100
Turbidity	93–99
Color	86–96
Nitrite	0
Phosphorus	0–47
Iron	87–98
COD	84–98
BOD	0–50

analysed for water quality parameters namely pH, conductivity, total suspended solid (TSS), turbidity, colour, nitrite, phosphorus, iron, chemical oxygen demand (COD) and biochemical oxygen demand (COD).

3 Result

In this study the concentration of the pollutants for each water sample were recorded during different time interval and presented in a table and figure for analysis. The summary of the overall performance in the form of average removal percentage is as stated in Table 1.

At the end of the experiment time, the RVFCW were effective in removing virtually all the TSS and about 99 % of turbidity. For colour, the removal was about 96 %. For iron and COD, the removal was about 98 % each. However, only partial of phosphorus and BOD were removed (47 and 50 % respectively). No nitrite removal was found in RVFCW treatment. For pH, the result indicates that it slightly approaches to neutral condition while conductivity always increases within time frame.

Table 2 shows in details the greywater parameter's value over the course of 48 h treatment.

For clearer comparison, the concentration of individual parameter is graphically generated as in Fig. 2.

For pH and conductivity, the chart shows the concentration recorded during the time interval instead of the removal percentage as per other parameter. Based on data in Fig. 2, each sample developed a same decreasing pattern except for nitrite, phosphorus and BOD concentration.

Table 2 Greywater quality using RVFCW within zero time until 48 h

Parameter	Sample 1				Sample 2				Sample 3				Sample 4			
	Raw	4 h	24 h	48 h	Raw	4 h	24 h	48 h	Raw	4 h	24 h	48 h	Raw	4 h	24 h	48 h
pH	5.11	7.29	7.34	7.48	5.87	6.78	7.14	7.40	7.82	7.17	7.25	6.99	8.17	7.79	7.66	7.04
Conductivity (μs/cm)	233	391	400	430	126	247	263	265	272	321	340	351	267	275	314	303
TSS (mg/L)	0.10	0.06	0.04	0	0.12	0.08	0.04	0	0.06	0.04	0.02	0	0.04	0.03	0.02	0
Turbidity (NTU)	50	18	4.47	1.47	46.5	15.5	0.92	0.69	17.2	8.79	2.25	1.21	26.2	11.8	1.08	0.93
Colour (PtCo)	435	170	93	60	428	155	17	16	263	139	29	26	282	155	32	23
Nitrite (mg/L)	0.029	0.075	0.014	0.001	0.012	0.006	0.050	0.022	0.049	0.093	0.259	0.400	0.024	0.085	0.250	0.450
Phosphorus (mg/L)	0.34	0.29	0.09	0.18	0.44	0.25	1.76	0.30	3.00	8.50	23.00	5.00	1.53	3.89	11.5	3.51
Iron (mg/L)	0.82	0.73	0.06	0.05	0.15	0.11	0.03	0.02	1.52	0.79	0.20	0.16	3.84	1.43	0.10	0.06
COD (mg/L)	230	140	60	38	200	120	46	32	118	54	33	18	96	41	13	2
BOD (mg/L)	36	162	108	96	144	114	36	96	30	12	6	24	12	54	30	6

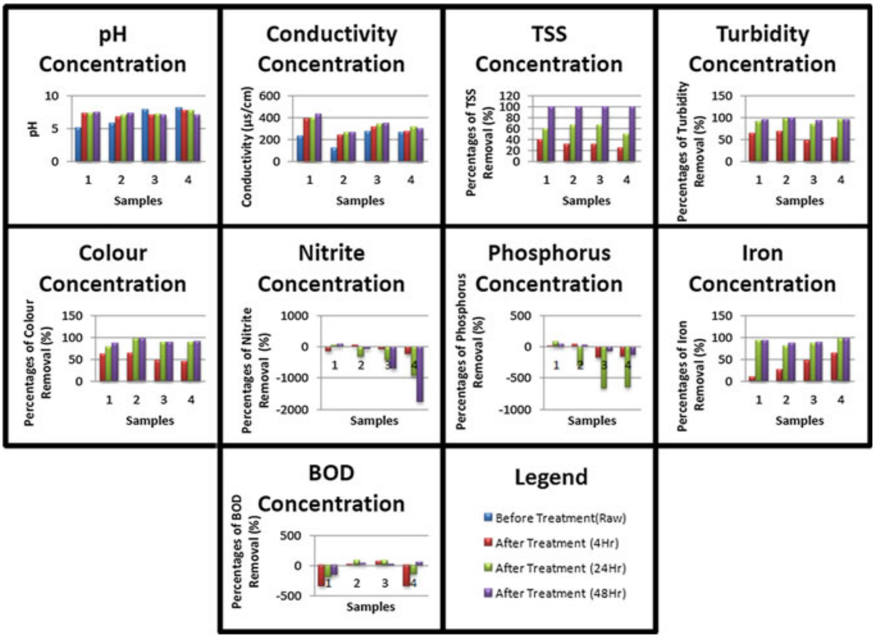

Fig. 2 Comparison of pollutants removal in different time scale

4 Discussion

After all the data has been obtained, analysis on the result was conducted in order to assess the effectiveness of RVFCW in treating greywater. As stated in previous chapter, the result has been encouraging by reflecting on the percentage of removal achieved at the end of treatment process. Details analysis of each parameter is as follows.

4.1 pH

The result shown that the pH value slightly approached to neutral. The reason was due to the uses of the limestone media in RVFCW. The previous research on limestone application in treatment of wastewater is founded effective in neutralize the pH. Koenig and Liu [5] stated that limestone supplies effective buffering capacity for pH control if the alkalinity in the influent wastewater is insufficient for complete autotrophic denitrification. Alkalinity supplied through limestone dissolution is a function of pH, which in turn depends on the initial alkalinity of the wastewater and progress of denitrification. The specific limestone dissolution rate, in gram limestone dissolved per unit gram of limestone is inversely proportional to pH for pH values lower than 7.1. Research by Aziz et al. [6] revealed that limestone able to increase the pH from the input value of pH 7. Moreover, the dissolution of limestone by acidic waters releases alkalinity, which in turn increases pH. As a result, the used of limestone media has major impact in neutralize pH of greywater.

4.2 Conductivity

In term conductivity, the result indicates the increment within hours. All samples have shown an augmentation or expansion in term of conductivity. From review of related literature it can be concluded that the higher value of conductivity was due to the higher ionic value. Yalcuk and Ugurlu [7] reported that the effluent conductivity values were higher than the influence conductivity values in all systems of wetland. The high value obtained due to high ion concentration in the effluent. Soltan and Rashed [8] further stated that the different media solutions exhibited increasing conductivity with increasing metal concentrations and duration of exposure to plants.

4.3 TSS and Turbidity

For TSS, the 100 % of removal was achieved. The reason was the amount of TSS was quite low in greywater sources compared if the sources taken from blackwater. Based on the finding from literature review, the removal of TSS was due to the sedimentation and filtration process in RVFCW. Stowell et al. [9] reported that the sedimentation process in wetland occurs due to gravitational settling of solids in wetland settings while filtration was occurs due to particulates filtered mechanically as water passes through substrate, and root masses. In case of sedimentation and filtration in RVFCW, the greywater passing through water hyacinth plant to filtration media which consists of limestone, gravel and sand due to gravitational settlings. Most of suspended solids were filtrated out and settled beyond the substrate of constructed wetlands. As a proved to the result of Stowell et al. [9], report by Yalcuk and Ugurlu as in [7] stated that more than 90 % removal of BOD_5, COD and TSS can be achieved in vertical surface flow (VSF) system, which make the result has become more obvious.

As TSS, similar trend was observed in turbidity removal. Reduction of turbidity as depicted in Fig. 2 due to sedimentation and filtration as well as removal of TSS. On the other hand, Gopal [10] reported that the water hyacinth were used for floc removal or settling in water treatment. The result is a significant decrease in turbidity due to the removal of flocs and also slight reduction in organic matter in the water. Sklarz et al. [11] further reported that 80 % of the turbidity and 75 % of the COD were removed within the first hour. As a result, the combination of RVFCW and water hyacinth were effectives in term of turbidity removal.

4.4 Color

As TSS and turbidity were decreased, the value of colour was as well decreased. Normally, the colour of wastewater increased with higher turbidity due to high amount suspended solid. This caused the water becomes more turbid and cloudy. The sedimentation and filtration process that occurred was able to remove TSS and turbidity effectively which directly impact on colour removal in RVFCW. As a result, the colour was founded nearly to 98 % of removal. So, it can be further conclude that the RVFCW was effective in term of colour removal.

4.5 Nitrite and Phosphorus Removal

In term of nitrite, very minimal and neglectable removal value was obtained in sample 1 and for other sample the result shows increment within hours instead. The increment of nitrite was proved by Kantawanichkul et al. as in [12]. In vertical flow systems process, greater oxygen transport ability than the horizontal subsurface flow beds and they are more effective for the mineralization of biodegradable organic matter and for nitrification through the activity of ammonia-oxidizing bacteria. Moreover, in vertical flow bed, a passive air pump (removing oxygen depleted air and introducing fresh air) supplies the oxygen required for the nitrification process. Green et al. as in [13] further discuss about nitrification process. In the study it was stated that, in nitrification process, ammonia is oxidized mainly to nitrate and nitrite. As long as value of nitrate was high, same thing went to value of nitrite. The nitrification process may add value of nitrate and nitrite. This finding was supported by Seidel as in [14] through statement that the higher nitrification efficiency was noted in vertical flow beds based on the Seidel model. So, as long as nitrification process occurs, the value of nitrite would increase.

Basically, as stated by Zurita et al. as in [15], the vertical flow constructed wetland (VFCW) were more effective for phosphorus removal. But the result indicates an increment of total phosphorus available in greywater. The reason was supported by Brix and Arias as in [16] through statement of the phosphorus removal in vertical flow constructed wetland is very limited, and it is not possible to obtain a sand bed medium that has a sufficient high capacity to bind phosphorus for a prolonged period. The report further stated that the removal of phosphorus in the vertical flow constructed wetland system will be fairly, low, typically 20–30 %. In the present study, result showed plants also affected phosphorus removal. The reason was phosphorus removal in wetlands may take place due to plant uptake [12].

4.6 Iron

For iron, the result showed that after 24 h treatment, the removal was nearer to 98 % of removal. The high iron removal was founded due to water hyacinth uptake the iron. Water hyacinth were effective in removing excess nutrient, heavy metals, toxic metal, minerals and organic chemicals, and herbicides from polluted water. The report further stated that the deprotonation reaction of water hyacinth during the uptake of metal ions from aqueous solution, as shown by decrease in pH [8]. Furthermore, Jayaweera et al. as in [17] founded that water hyacinth were most efficient in phytoremediating iron as these plants showed a highest removal efficiency of 47 % during period of optimum growth at the 6th week. In heavy metal removal, Aziz et al. as in [6] founded that limestone was capable to remove more than 90 % of heavy metal from a solution of 2 mg/L.

4.7 COD and BOD

After 24 h, the results shown the COD removal was about 90 % removal. This result can be supported by Yalcuk and Ugurlu as in [7] which founded that more than 90 % removal of BOD_5, COD and TSS can be achieved in vertical surface flow systems. Sklarz et al. as in [11] also reported that 80 % of the turbidity and 75 % of the COD were removed within first hour in recirculating vertical flow constructed wetland. The use of water hyacinth in wastewater was founded effective by Jianbo et al. as in [18] with 64.4 % of COD removal rate. Finally, it shown that, the combination of RVFCW with water hyacinth was effective in COD removal.

Initially, RVFCW was effective to remove the BOD in greywater [18]. But, BOD was required for decomposition of organic matter by microorganism. However, at the same time oxygen were required for process of nitrification of nitrite and nitrate by ammonia. So, the amount of the BOD was increase within the time and unable to achieve optimum removal efficiency.

5 Conclusion and Recommendation

From the study, the RVFCW system was proven to have a potential in greywater treatment. Most of water quality parameters showed high removal efficiency except for nitrite, phosphorus and BOD. A less efficiency of nitrite removal was due to nitrification process in RVFCW. Therefore, it could be concluded that higher greywater concentration was more efficient in removing pollutants from greywater due to the sedimentation and filtration besides the presences of microorganism for biodegradation.

Besides, the study showed uptake of heavy metal by plants increased with increasing metal concentrations. *E. crassipes* had higher capacity to accumulate iron. However, if the heavy metals concentration exceeded the ability of the plant to adsorb, it will resulted in plant wilting due to the toxic impact thus increased the metal and organic content of greywater. On the other hand, the use of Limestone was also founded effective in removal iron as heavy metal and also to neutralize pH of greywater. Finally, combination of RVFCW with *E. crassipes* as wetland plant and limestone media were gives better performance on removal pollutant in greywater.

From this study, there are many possibilities of further research scopes to be investigated. For future work, following recommendations were suggested to improve efficiency of RVFCW:

- To study greywater efficiency when different number of plant is introduced in the constructed wetland. The uses of water hyacinth in greywater treatment only limited to certain parameter. Some of the parameter such as nitrite and phosphorus not totally removed. Process combination of wetland plant must be studies to determine the performance of wetland plant. Some of the wetland plant not able to perform in combination.
- To introduced activated sludge to provide additional microorganism and better aeration method to be implemented in the experimental setup. This is to cater the removal of BOD as this study was only able to achieved not more than 50 % efficiency.
- To use soil media with emergent macrophyte based. The uses of soil with combination of emergent plant may be effective on removal pollutant. Not only plant uptakes the pollutant in a root and leaves but may be soil uptake some of pollutant.
- To use different media for filtration to treat greywater. The use of other media may be effectives in removal certain parameter. Combination of good media will effect the efficiency of RVFCW.

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