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Ceramic Tile Waste for Treating Laundry Greywater

Radin Maya Saphira Radin Mohamed[1,2]*, Al-Gheethi AAS[1,2], Mohd Shauqi Lutfi Ahmad[1], Siti Asmah Bakar[1], Sabariah Musa[1] and Amir Hashim Mohd Kassim[1]

[1]*Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), 86400 Parit Raja, Batu Pahat, Johor,Malaysia*

[2]*Micropollutant Research Centre (MPRC), Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia*

ABSTRACT

Greywater traditionally receives the least attention compared to other aspects of environmental sanitation. In Malaysia, most of village houses discharged lots of significant portion of greywater into stream without any treatment. Laundry Greywater (LGW) is one of the largest portion of greywater that has been directly discharged to the stream. The aim of this study was to identify the physical and chemical characteristic of laundry greywater quality from the houses and also to evaluate the efficiency of using ceramic waste coarse aggregate filtration for LGW treatment. The effectiveness of the treatment systems was optimized with different Hydraulic Retention Time (HRT) and volume of samples by using Response Surface Methodology (RSM). The samples were taken from the direct discharge point of the laundry greywater at two houses. The results revealed that the efficiency of designed filtration system depended on HRT and volume of samples. The highest Chemical Oxygen Demand (COD) removal from 1 L of LGW and after 3 hrs was 43.31%, while the highest removal of orthophosphate (PO_4) (100%) and sodium (Na) (27.48%) were recorded with 2 L and after 2 hrs. It can be concluded that the ceramic waste coarse aggregate filtration was effective in reducing the pollutants in the LGW before the final disposal into the environment.

Keywords: Ceramic waste, laundry greywater, optimization, quality, RSM, removal

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E-mail addresses:
maya@uthm.edu.my (Radin Maya Saphira Radin Mohamed)
adel@uthm.edu.my (Al-Gheethi AAS)
mohdshauqi94@gmail.com (Mohd Shauqi Lutfi Ahmad)
hf150087@siswa.uthm.edu.my (Siti Asmah Bakar)
sabariah@uthm.edu.my (Sabariah Musa)
amir@uthm.edu.my (Amir Hashim Mohd Kassim)
* Corresponding author

INTRODUCTION

Greywater is one of the most significant sources of pollution that originates from showers, sinks, dishwashers, and washing machines. Among different types of the greywaters, the laundry greywater from

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washing machines contains high concentration of nitrogen, phosphate, heavy metals, linear alkylbenzene sulphonate (LAS), volatile organic acids and alcoholic compounds resulted from the utilization of detergents and can cause toxic effects on the ecosystem and biodiversity (Jefferson et al., 2004; Mohamed et al., 2017). Therefore, these wastes should be subjected for a treatment process before the final discharge into the environment and water system.

The filtration methods are the one of the most efficient treatment process for the greywater. These filters are designed from several layers of materials such as coconut shell cover, saw dust, charcoal, bricks and sand and have exhibited a detectable efficiency in reducing COD, biochemical oxygen demand (BOD), total suspended solid (TSS) (Mohamed et al., 2016; Parjane & Sane, 2011). The utilization of filtration system is more applicable and can be considered as a feasible alternative to conventional treatment plants in rural region since they are characterized by highly potential for COD, TDS, TSS, total hardness, oil and grease, anions and cations removal (Parjane & Sane, 2011). Moreover, the filtration is an environmental friendly, without chemical operation, low cost and resourceful plant for rural development (Parjane & Sane, 2011; Wen et al., 2000).

Ceramic waste coarse aggregate filter from the ceramic waste has a potential to be use as primary treatment at rural residential. The ceramic water filter works through a combination of physical and chemical disinfection whereby the pore spaces in the porous ceramic filter element are small enough to trap pollutants bigger than water molecule (Mohamed et al., 2018). Ceramic has small pore diameter of less than 30μm and good chemical resistance to weak acids and weak bases. The use of ceramic as filtration media is effective to reduce COD concentration in water. Wen et al. (2000) stated that the ceramic was very effective for the reduction of TSS and ammonia nitrogen (NH_4-N) in combined greywater which was up to 100% and 95% efficiency. Malapane and Hackett (2012) reported that efficiency of ceramic in reducing turbidity in domestic wastewater reached 83%-99%.

Many of the researchers including Mohamed et al. (2014), Chan et al. (2014) and Malapane and Hackett (2012) have investigated the treatment of greywater from bathroom, laundry and kitchen respectively from bathroom, laundry and kitchen but there is a lack of study that needs a specific treatment for LGW. Nonetheless, Parjane and Sane (2011) and Wen et al. (2000) stated that, ceramic waste coarse aggregate filter was smaller in size and the simple design had led to better performance in reducing all parameters found in greywater. The filter media can be produced locally, using local resources and labour. However, the optimization of filtration process is a critical point in these systems. Therefore, the aim of this study is to optimize the operating process of proposed sustainable treatment system for reducing COD, PO_4 and Na concentration.

MATERIALS AND METHODS

Ceramic Waste Collection

Ceramic waste was obtained at Parit Bengkok areas which was left over from house construction. The waste materials were tightly packed in a plastic bag and transported to the laboratory and then subjected for segregation process to remove the other materials and were stored in the laboratory under room temperature (25±2^{o}C). Prior to the investigation, the chemical composition of the ceramic wastes were observed as in Table 1.

Table 1
Chemical composition of ceramic filter media

Formula	Concentration
S_1O_2	10.5%
Al_2O_3	43.60%
C	0.10%
K_2O	4.17%
Fe_2O_3	3.74%
Na_2O	1.38%
TiO_2	0.76%
MgO	0.76%
CaO	0.89%
S	0 < LLD

Laundry Greywater Sampling

The sampling location of the laundry greywater used for the analysis was obtained at Parit Bengkok areas, a village area in Batu Pahat, Johor, Malaysia. The samples of laundry greywater were obtained from two different sample points which directly discharge laundry greywater into the main drain. Samples were collected during the laundry activities by the occupants of the houses and were taken from the direct discharge of the laundry pipes before discharge to main drainage. Greywater was collected from two houses having similarities in terms of number of occupants. The discharge point for collecting laundry greywater is shown in Figure 1.

(a) (b)

Figure 1. (a) First sample of laundry greywater (b) Second sample of laundry greywater (Photo was taken on 14 April 2017)

Ceramic Waste Filter Media for Laundry Greywater Treatment

The ceramic filter system of the laundry greywater is depicted in Figure 2. The designed filter was fixed at the discharge point of laundry greywater. The treatment system was designed in prototype, the tank used was a cylindrical shape (36130.4 cm^3), the filter had two pipes consisting of the inlet and outlet channels of the constructed filter. The laundry greywater inlets were covered with net for pre-screening of trapped materials such as hair, soap, toilet paper, and diapers to prevent them from entering into the filter. Adjustable water pumps (13.2 W) (Fisher Scientific Malaysia) were used for the injection of the laundry greywater from the storage tank to the treatment system and lastly to the drainage or stream. Valve was installed based on the designed flow rate (Q) which was 17.36 mL/min per minute at the inlet and outlet of the filter. The retention time was investigated to determine the potentials of the designed treatment system. The temperature of laundry greywater samples used in the study was 25 ± 2°C.

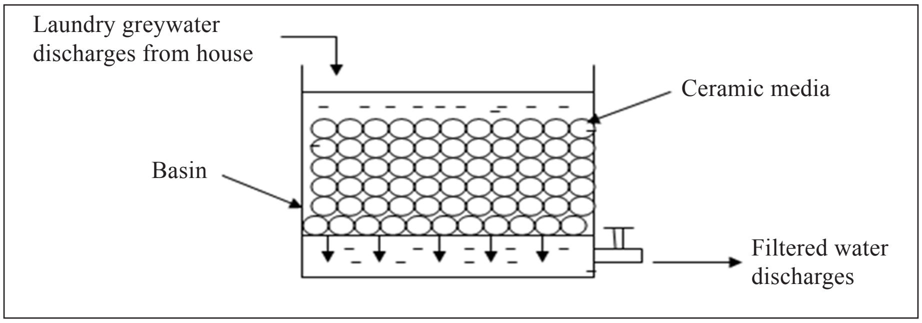


Figure 2. Design of multi-layer of laundry greywater treatment system

Optimization of Operating System of the Ceramic Filtration

The design of the operational parameters of the ceramic waste filter media for bathroom greywater was constructed using the central composite design (CCD) software. The parameters to be optimized were the hydraulic retention time (HRT) and volume of samples. The investigation was conducted to determine the effect of the factors on the removal of COD, PO_4 and Na. The parameters optimized are presented in Table 2. The statistical significance of the investigated parameters was observed using the analysis of variance (ANOVA).

Table 2
Optimized condition of the independent variables

Factor	Symbol	Level		
		Low(-1)	Middle (0)	High (+1)
Hydraulic retention time (HRT) (hours)	x_1	0.59	2.00	3.00
Volume of samples (L)	x_2	1	2	3

RESULTS AND DISCUSSIONS

Greywater Characteristics

The variability of the characteristics of the two houses investigated was compared to the findings of other researchers in the literature. Table 3 shows the raw characteristic of LGW. The data were compared to the previous research from Lopez Zavala et al. (2016), Braga and Varesche (2014) and Parjane and Sane (2011) to assess the level of contamination of the laundry greywater sample.

Table 3
Characteristic of laundry greywater before treatment compared with previous studies

Parameters	Unit	Laundry greywater		Lopez Zavala et al. (2016), Braga and Varesche (2014), Parjane and Sane (2011)
		House A (powder detergent)	House B (liquid detergent)	
COD	mg/L	228.00	598.00	327 - 4796
PO_4	mg/L	88.55	2.66	0.012 - 279
Na	mg/L	461.60	174.70	32.28

Table 2 shows the value for the raw water characteristic of laundry greywater for two different houses in this study. From the experiment of raw water sample, the range of COD for laundry greywater for house A and house B were 228 mg/L and 598 mg/L, respectively. Compared to Lopez Zavala et al. (2016), Braga and Varesche (2014) and Parjane and Sane (2011), COD values for house B were in range from 327 mg/L to 4796 mg/L which indicated that liquid detergent contributed more toxicity. Therefore, concentration of PO_4 was high from house A which was 88.55 mg/L. It indicated that powder detergent contained more PO_4 than liquid detergent which was 2.66 mg/L. Based on literature review, concentration of PO_4 is in the range of 0.012 – 279 mg/L which is complied by house A and B. It shows that PO_4 concentration of laundry greywater is normal at average values. Laundry greywater from house A had higher concentration of sodium with 461.60 mg/L compared to house B with 174.70 mg/L. Sodium content reported from past studies is 32.28 mg/L which is lower than raw laundry greywater of house A and B. This showed that the high amount of detergent was used through washing process from house A and B thus contributing to high sodium content. Therefore, the use of powder detergent contributes to more toxicity in water because it contains high amount of COD, PO_4, and Na.

Regression Coefficient of Operating Parameters

The parameters for the study were analysed using RSM design expert. The result of the actual and predicted values for the operational parameters are illustrated in Table 4.

Table 4
Regression coefficient of operating parameters

Run	HRT (hour)	Vol. (L)	COD (mg/L)		PO_4 (mg/L)		Na (mg/L)	
			Actual	Predicted	Actual	Predicted	Actual	Predicted
1	2	2	142	143	85.3	84.26	494.4	486.38
2	3	1	198	188.98	83.15	83.51	540.4	527.97
3	2	2	163	175.76	85.83	85.32	507	524.59
4	1	3	148	143	83.29	84.26	492	486.38
5	3	3	149	158.02	85.41	85.05	502.7	515.13
6	2	2	147	156.02	78.73	78.37	494.9	507.33
7	0.59	2	173	163.98	80.65	81.01	471.4	458.97
8	3.41	2	139	143	83.02	84.26	456	486.38
9	2	2	140	143	84.1	84.26	486.7	486.38
10	1	1	146	143	85.57	84.26	502.8	486.38
11	2	2	161	148.24	84.04	84.55	567.3	549.71

From the result of the optimized condition, it was observed that optimum removal of COD, PO_4 and Na was achieved for the actual and predicted values using 1 hour HRT and 1 liter volume of samples. The regression coefficient was used to formulate the regression equation from the design treatment system. Based on data resulted from RSM analysis, COD concentration after treatment process is lower than predicted value. It indicates that RSM analysis in COD removal is not very efficient from most of the run. However, PO_4 and Na concentration after treatment process are above the predicted value. It shows that this study is successful in conducting RSM on HRT and volume of samples. The linear, quadratic and the synergistic effect of the parameters for the reduction of COD of the laundry greywater are illustrated in Table 5. This is to describe the significant relationship between the reduction of contaminants in laundry greywater and selected factors.

Table 5
Regression coefficient and their significance of the quadratic model for the reduction of COD from laundry greywater

Source	Sum of Squares	DF	Mean Square	Mean Value	Prob> F
Model	2441.82	5	488.36	3.43	0.10
A-HRT	757.16	1	757.16	5.32	0.07
B-Vol	132.25	1	132.25	0.93	0.38
A^2	515.71	1	515.71	3.63	0.12
B^2	477.79	1	477.79	3.36	0.13
AB	182.25	1	182.25	1.28	0.31
Residual	711.09	5	142.22	-	-
Lack of Fit	651.09	1	651.09	43.41	0.003
Pure Error	60	4	15	-	-
Cor Total	3152.91	10	-	-	-

Note. A = Main factor (Ceramic size); B = Main factor (HRT); A^2 = Secondary Factor; B^2 = Secondary factor; AB = Combination between A & B.

The effect of the examined factor on the reduction of COD is shown in Table 4. The result shows that the factor A and B had a negative significant linear effect on the reduction of COD. For the coefficient A^2 and B^2, it was observed that the regression coefficient had positive significant quadratic effect on reduction of COD. Meanwhile the synergistic effect of the factor A and B gave a negative significant linear effect. Therefore, it is observed that the combination of hydraulic retention time and volume of samples would not affect the COD removal in the laundry greywater. The regression coefficient is represented in equation 1, 2 and 3.

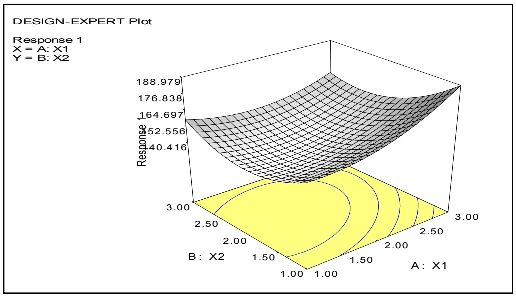
$$Y_{COD} = +26.47-10.06A+3.19B+1.28A2-1.34B2-0.12AB \text{……….} (1)$$

$$Y_{PO4} = 63.35+3.51A+16.08B+0.34A^2+-2.61B^2-2.30AB \text{………..} (2)$$

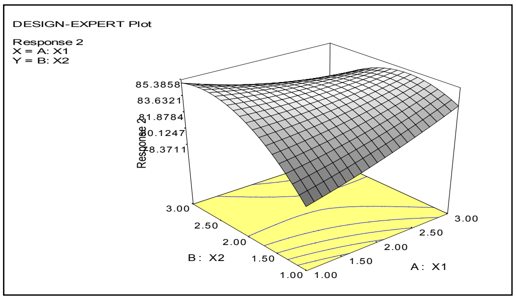
$$Y_{Na} = 521.83-72.02A+60.76B+25.39A^2 -9.42B^2-19.20AB \text{.……} (3)$$

Interactions between Operating Parameters

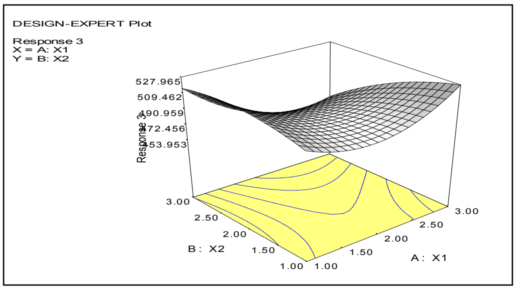
Three-dimensional response surface plot for the reduction of COD, PO_4 and Na in raw laundry greywater using ceramic filter media as a response of the interaction between independent factors; A) Hydraulic retention time B) Volume of samples was achieved according to RSM expert design. The three-dimensional graph illustrated the relationship between the ceramic sizes and hydraulic retention time in the reduction of the investigated parameters.



(a)



(b)



(c)

Figure 3. (a) Reduction of COD (mg/L); (b) Reduction of PO_4 (mg/L); and (c) Reduction of Na (mg/L)

The interaction effects of COD, PO_4, and Na reduction were studied by plotting 3D surface curves. The plotting of 3D surface curves of the calculated response from the interaction between the ceramic sizes and HRT are shown in Figure 3. Based on the 3D graph, it showed that the increased HRT will increase the reduction of COD in LGW. However, the volume at 1 and 3 L samples showed the optimal rate of COD reduction. However, the 3D graph of PO_4 showed that the increase of HRT will increase the reduction of PO_4 in LGW. In addition, the increase of volume will also increase rate of PO_4 reduction. Therefore, the 3D graph of Na shows that the optimal reduction of Na is at 1 and 3 hours of HRT. Therefore, the highest rate of Na reduction is at mid-level 2 L volume of samples.

CONCLUSIONS

The quality of laundry greywater based on physiochemical parameters investigated from houses shows high concentration in COD, PO_4 and Na resulted from detergent used. The filtration system using ceramic waste coarse aggregate was optimized with variation of HRT and volume of laundry greywater. Analysis of the RSM design expert had shown that the optimal operation parameters for the reduction of COD, PO_4 and Na was recorded at 2 hours HRT and 2 liter volume of samples. The observed and predicted reduction of COD, PO_4 and Na were 33.12%, 4.98% and 2.66% respectively. It can be concluded that HRT and volume of samples are factors that can influence the pollutant removal of laundry greywater. Therefore, ceramic waste coarse aggregate filter has potential for the removal of contaminant in laundry greywater.

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