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Greywater Treatment using Pottery Waste Ceramic Filter

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ABSTRACT

Most village houses in Malaysia discharged lots of significant portion of greywater into stream or drains without any treatment. This phenomenon of direct disposal of greywater into the environment caused environmental risk, especially to water body. This study aimed to assess the quality and treatment of greywater discharge using pottery waste ceramic filter (PWCF) for safe disposal. Greywater samples were collected from 27 village households located at Kampung Parit Sempadan, Parit Raja using grab sampling method. Greywater was treated by using PWCF. The effectiveness of the PWCF was optimized using different sizes (0.25, 0.60, and 1.18 mm) of ceramic filter media at different hydraulic retention times (HRT: 1, 2, and 3 h). The t-test analysis showed significant differences between greywater from the two drainage distances. The results revealed that a distance within 81–100 m was significant to the influence of gender and the number of household occupants of the greywater discharged. The results of this study highlight that PWCF reduced the concentration of COD, BOD and TSS in greywater by 99.4%, 74.3 and 100% respectively using particle size of 0.25 mm and HRT of 3 hours. Finally, it deduced that the use of PWCF was effective and can enhance the quality of greywater for safe disposal.

Keywords Ceramic Filtration, Hydraulic Retention Time, Greywater Quality, Reduction

INTRODUCTION

Greywater is the water comes from household activities, which involve kitchen sinks, laundry, showers, baths, and dishwashers. These wastes flow directly into the drains from pipes, thereby constituting poor environmental sanitation and pollution problems. Greywater consists of 85% of the total domestic water consumption in urban slums of most developing countries (Katukiza et al. 2015). Average production of domestic greywater is 98 L per inhabitant per day in Greek cities, which equivalent to 70–75% of total household generated wastewater (Noutsopoulos et al. 2015). In Uddin et al. (2016), the domestic greywater effluent from hand washing sinks, kitchen water usage and laundry activities were reported to contain chemical oxygen demand (COD) in the range of 35–70,032 mg/L, pH 3–10, total suspended solids (TSS) 168–9280 mg/L, and ammonium ions (NH_4+) 0–504.5 mg/L. Greywater can also be contaminated with *Enterococcus sp., Salmonella* and enteropathogenic *E. coli* (EPEC) (Ramprasad et al. 2017) due to the accumulation of toxic pollutants, which can affect the aquatic environment.

Mohamed et al. (2013) investigated the greywater characteristics and their influence on greywater quality in Malaysia. Some of the considered factors include house types, number of occupants, type of greywater system, and landscape characteristics. It was generally observed that the concentration of BOD, TSS, and pH were the most violated parameters and their values were reported to be out of the stipulated guideline range. Water consumption behaviour according to the household activities have tendency to escalate the demand on water resources. The problem in selecting the treatment system of greywater dealt with easy installation and less maintenance. Consequently, the discharge of significant portion of greywater may increase the pollution load into water bodies. Similarly, cultural preferences, religion or behavioural differences which varies geographically may have impact on the greywater discharge (Al-Gheethi et al. 2018). Water consumption rate—particularly in the context of greywater discharge—may vary regionally depending on the practices and orientations of different regions. For example, some regions in a Muslim dominated country like Bangladesh used urine diversion dehydration toilets (UDDT) as an alternative to the conventional treatment system (Uddin et al. 2014). However, despite the use of UDDT as provision for the collection and separation of urine, faeces and greywater, the monitoring policy in place for the discharge of the separated wastes, especially greywater in the drains becomes the major drawback. Meanwhile, toilet flushing is preferred than the use of UDDT in Pakistan. Therefore, the volume of daily water consumption might increase the production and the discharge of greywater in water ways.

Filtration media is used for the treatment of various greywater but it depends on the availability and suitability of materials (Zipf et al. 2016). Locally sourced low-cost materials as filter media have been reported in literature related to the treatment of domestic greywater. They are inexpensive and has a sustainable means. Some of the materials including synthetic fibres have the capacity to be suspended in the greywater during washing and drying cycles, and are very effective in the sewage treatment plants. This is because synthetic fibres are not readily decomposed by the activities of bacteria (Zubris and Richards 2005). The application of peat filter media in the study of Mohamed et al. (2014) revealed the feasibility of the filter media for the treatment of greywater in Malaysia. It was observed that the BOD concentration was reduced by 52, 65, and 74% respectively for the 7th, 14th and 28th day of the filtration process. Since the peat surface was positively charged, the negatively charged solutes in the greywater—caused by the presence of organic compounds—were expected to adhere to the surface of the peat filter media. Similarly, Dalahmeh et al. (2014) explored the use of bark, charcoal, and sand filters for the treatment of greywater. It was observed that the influence of the hydraulic retention time (HRT) and the organic loading rate influenced the characteristics of the greywater. The investigated parameters were BOD, COD, total nitrogen (TN) and total phosphorus (TP) at different conditions of loading rate. A decrease was observed in the efficiency of bark filter for the reduction of COD from 74 to 40%. In the application of charcoal and sand filters, the reduction was observed from 76 to 90% and 65 to 83% respectively while the organic loading rate increased from 13 to 76g BOD5 m−2 day−1 for all filters. However, the TP decreased from 81 to 73% for bark filters while, a decrease in HRT reduced the pollutants in all filters.

The use of ceramics as filter media for the treatment of domestic greywater is getting research attention. Ceramic membrane was used in the study of Ali et al. (2017) to investigate the removal of heavy metals, namely Pb^{2+}, Cd^{2+}, and Cu^{2+} ions from aqueous media. Results from the investigation showed that more than 99% reduction of the heavy metals was achieved. The use of ceramic filter submerged in a membrane bioreactor achieved 97–100% removal of BOD and >88% of total organic carbon (TOC) (Hassan et al. 2015). Hybrid photocatalytic ceramic membrane system achieved >90% of dissolved organic carbon (DOC) (Song et al. 2017). However, the efficiency of the ceramic medium to reduce pollutions from greywater and characterisation of ceramic material used as a filter medium has not been investigated in depth. The objective of the present research is to study the influence of household activities toward greywater discharge and to measure the greywater filtration system by using pottery waste ceramic filter (PWCF) for the treatment of greywater at different operating conditions.

MATERIALS AND METHODS

GREYWATER DISCHARGE SURVEY

A well-designed questionnaire via interview were distributed to the residents comprising 27 housing units in a village at Parit Raja, located 23 km away from the capital of Batu Pahat, Johor, Malaysia. The purpose of the interview was to get information on family characteristics and family household activity that influence the greywater discharge quality and volumes. Factors considered in the questionnaire include number of persons/households, occupations of residents, water usage based on water bills, and general household practices. Respondents were occupants of the houses with the distance of drainage for each house to the ditches as follows: 0–20, 21–40, 41–60, 61–80, and 81–100 m respectively. The questionnaires via interview were conducted prior to the experimental analysis of the greywater characteristics. Data of frequency schedule attached in the questionnaire form were used to project the time of effluent discharged from each house. The volume of greywater discharged by point source was measured for each sampling using container with volume scale (Mohamed et al. 2016).

GREYWATER SAMPLING

Grab sampling of greywater was collected from the drain at Kg Parit Sempadan between January to March 2017 and stored in bottle containers according to the methods described in APHA (2012). The temperature of the greywater was determined at the time of sampling (25±2°C). A flow measurement from the greywater source was obtained using a cylindrical bucket located at the source outlets of the houses. Measurement from the greywater source was carried out three times and the average loading of the greywater was obtained at any given time to assess the effect of different sampling conditions on the treatment.

The sampling for the greywater was conducted in three periods (morning, afternoon and night) with each sampling collects 1 L sample. This was due to the variety of activities carried out in the houses. Greywater samples were stored in a tightly packed containers and were transported to laboratory for chemical and physical analysis (pH, BOD5, COD, TSS, chloride, bromide and sulphate) according to the standard method of wastewater storage and preservation (APHA 2012). Sampling of the greywater discharged from the household is illustrated in Figure 1.

FIGURE 1. The direct discharge of greywater from household to the drain at the village residential

POTTERY CERAMIC WASTE SAMPLING AND PROCESSING

Pottery ceramic wastes used in this study were obtained at ceramic industry located in Kluang, Johor. The ceramic wastes were separated from foreign materials and packed in an enclosed 25 L container before it was transported to the laboratory. Then, the ceramic wastes were crushed using a mechanical crusher, followed by grinding using a ball mill grinder to obtain the desired working particle sizes. The process for the preparation of the ceramic particle sizes is illustrated in Figure 2–5. The method for sampling and processing of the pottery ceramic waste was according to the standard procedure (APHA, 2012). The grinded particles were sieved to the working sizes (0.25–1.18 mm) to optimize the filtration process (Nnaji & Emefu 2017). Each size of the ground ceramic waste was placed in a clean air tight container to avoid microbial contact with the prepared media.

DESIGN OF THE POTTERY WASTE CERAMIC FILTER (PWCF)

The schematic diagram of PWCF designed for the filtration of greywater is depicted in Figure 2. In the storage tank from the housing units, the influent sample was taken from the upstream of the process treatment units via a connecting valve at the outflow concentration of 30 L/day ± 20% of the discharged effluent per day within the period of sampling. The treatment chamber was made using a rectangular sampling tank with cross-sectional area of 1400 × 760 mm. The tank contained the pottery waste ceramic filter media. It used the predetermined working particle sizes for the treatment process. The valve was installed between the filtration unit and the disinfection tank to obtain the effluent grab sample from the disinfection tank. Finally, the treated and the disinfected household greywater effluent was discharged into the storage tank for irrigation purposes.

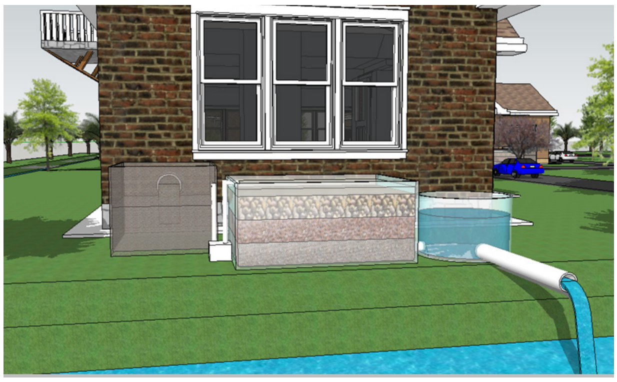

FIGURE 2. The greywater treatment using pottery waste ceramic filter (PWCF)

The efficiency of the filtration media to reduce dependent variables (BOD5, COD, turbidity, and pH) was investigated as a function of independent variables (ceramic particles size of 0.25, 0.6 and 1.18 mm; HRT 1, 2 and 3 hrs). The reduction efficiency of dependent variables in the greywater was calculated according to Equation 1:

$$Removal\ (\%) = \left(\frac{Co - Ce}{Co}\right) \times 100\% \qquad (1)$$

where Co is the initial concentrations of dependent variables, Ce is the final concentration of dependent variables in filtrated greywater

SURFACE MORPHOLOGY OF THE POTTERY WASTE CERAMIC FILTER (PWCF)

The surface morphology of the pottery waste ceramic filter (PWCF) media was investigated before and after the filtration process using the scanning electron microscopy (SEM-JOEL 6480) located at Environmental Analysis Laboratory, Faculty of Civil Engineering and Built Environment (FKAAB) to obtain the microstructure of the filter media. Characterisation of the PWCF media was performed at electron beam accelerated voltage to obtain the micrographs with better resolution of the media. Prior to the investigation, samples were coated with platinum target to improve the conductivity of the media surface.

The chemical composition of the PWCF was examined using the X-ray diffraction (XRD) located at Microelectronics & Nanotechnology - Shamsuddin Research Centre (MiNT-SRC) to obtain the crystalline structure of the media. The XRD was conducted using a Rigaku D/MAX diffraction at 40 Kv at a 2- theta diffractometer using a wavelength of 1.54 μm within the range of 0–100°. The crystalline arrangement patterns of the media were obtained using diffracted beams and were analysed using the XPERT XRD programme software installed in personal computer (Khorsand et al. 2014). Identification of the crystalline phases was achieved using the database of International Center for Diffraction Data for Inorganic Substances ICSD (Bernando et al. 2016). Patterns of the crystalline and the chemical compounds present in the filter media. The chemical composition on the media surface was obtained using energy dispersive X-ray spectrometer (EDX) to determine the available elements; high resolution scan spectra were obtained at 30kV to give the chemical attachment of oxygen, silicon and aluminum on the media and the percentage by mass of the contributing elements.

RESULTS AND DISCUSSION

FACTORS INFLUENCING THE GREYWATER DISCHARGE

Results from the questionnaire distributed via interview analysed household activity based on the seven occupants selected of different gender and the frequency mean. Clearly, greywater discharge analysis focused on the following sources: bath (storage), bath (shower), basin, bathroom cleaning, laundry, kitchen (dishwashing), and kitchen (cooking). The percentages of greywater discharge from the sources are illustrated in Figure 3.

The greywater discharged from the point of origins in the households were varied based on the utilisation of water, household habits, and also as a result of different

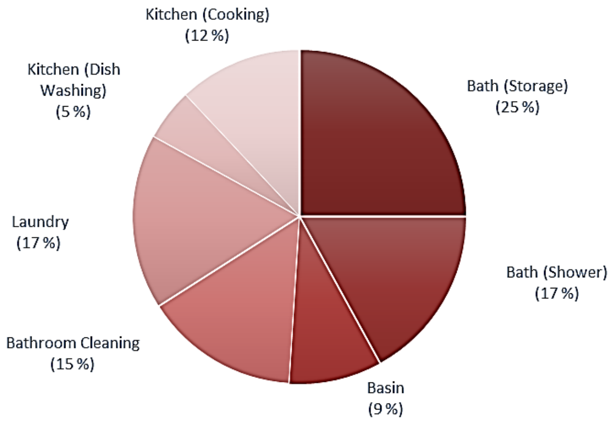

FIGURE 3. The percentage of greywater sources discharged from 27 village houses in Parit Raja, Johor, Malaysia

forms of activities carried out in each section of the house. Figure 8 shows that the greywater discharged from the houses in percentages are bath (storage) 25%, bath (shower) 17%, basin 9%, bathroom cleaning 15%, laundry 17%, kitchen (dishwashing) 5%, and kitchen (cooking) 12%. From the figure, bath (storage) contributes to the maximum percentage of greywater discharge, followed by the discharge from bath (shower), kitchen and laundry.

The volume of the greywater discharged from the laundry was measured on a weekly basis due to the differences in the frequency of laundry activities among the households. The percentage of the greywater discharged from different units in the residential areas from previous studies was compared to the present study. The results are presented in Table 1.

The increase in the greywater discharge depends on the availability of water and the per capita water used (Al-mughalles et al. 2008). Table 1 estimates the greywater discharged by four countries in Asian, Europe, and the Middle East with different climates and cultures. According to Table 1, the highest greywater discharge was from bathroom sources (25%) while the lowest was from the kitchen dish washing (5%). The results obtained from Parit Raja were similar to the results obtained from the previous research conducted at Parit Bengkok, Malaysia (Mohamed et al. 2015), in which bathroom, kitchen, and laundry were the primary sources of greywater discharge. This research also agrees with previous studies regarding higher greywater discharged from bathing activities (storage and shower), i.e., 42% and the lowest one from hand basin (9%) due to activities of facial and hand washing. The high volume of shower activity (51%) in Oman may be attributed to high temperature, which necessitates higher frequency of bathing occasioned by the likelihood of persistent sweating. Conversely, in Sana'a, Yemen, lower greywater discharged was noticed due to lower consumption of water resource as a result of water shortage and scarcity.

TABLE 1. The household greywater quantities (percentage) derived from this study compared with previous studies

Location	Bath Storage	Bath Shower	Bathroom Cleaning	Basin Hand Washing	Basin Facial	Kitchen Dish Washing	Kitchen Cooking	Greywater %	References
Oman	-	51	-	7	-	-	34	82	Jamrah et al. (2008)
Sana'a	-	18	-	32	-	-	37	87	Al-mughalles et al. (2008)
Greece	41	-	-	10	-	8	15	58	Antonopoulou et al. (2013)
Parit Bengkok	52	-	-	-	-	-	37	100	Mohamed et al. (2015)
Parit Raja	25	17	15	9	-	5	12	100	Present Study

However, the greywater discharged in Parit Raja as the site location in this study was a result of two factors: in-house and onsite factors. In-house factors can be referred to as demographic profile (number of occupants, occupation, gender category) and household activities (greywater sources, water bills, greywater discharged by each activity and frequency). The onsite factor was the drainage distance connected from point sources to the ditches. Therefore, to determine the influence of the in-house and the distance to the drainage pollution due to greywater discharged, a paired-sample t-test was conducted to compare both factors and their effect to the greywater discharged. The results demonstrating the relationship between the factors, including the household activities and distances are presented in Table 2. The t-test analysis demonstrated that when greywater discharged is influenced by an in-house factor including different gender category or number of occupants, the tendency for pollution to occur in the ditches is high. Due to the significant difference of the score, $p < 0.05$, it was observed that both distance and greywater discharged variable is not dependent on each other ($p > 0.05$).

The quantity of the greywater discharged is affected by in-house factors but independent of ex-house factor and area of residence (Jamrah et al. 2008). These findings suggested that the in-house factor has a significant role to the greywater discharged in the village houses. Household activities were mostly the principal source of this study, excluding kitchen (dishwashing). Dishwashing activities was not a major source of greywater discharge because the frequency of activity depends on the active periods; for example, during the cooking period.

TABLE 2. The relationship between household activities and drainage distance

Distance (m)	Household Activities	Paired-Sample T-Test, t	Significant, p < 0.05
0–20	Bath (Storage)	−2.722	0.035
21–40	Bath (Storage) Bath (Shower)	−4.171 −3. 841	0.006 0.013
41–60	Bath (Storage) Basin	3.200 9.378	0.019 0.015
81–100	-	-	-
0–100	Bathroom Cleaning Laundry Kitchen Cooking	−3.425 −-3.519 3.222	0.027 0.024 0.032

continue...

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A partial correlation was conducted to determine the relationship between gender and greywater discharge as a result of activities on the number of occupants across different drainage distance groups. As shown in Table 3, for drainage located within the distance of 0–20 m, there was a moderate, negative partial correlation between gender and greywater discharge influenced by the activities of some occupants, which is not statistically significant ($r = −0.547$; $p = 0.204$). According to Gormey and Dickensen (2008), the difference in the types of building and the types of activities of the occupants determines the quality of the greywater characteristics in the drains. However, for the drainage located within 41 to 60 m, the result shows that there was a weak, negative partial correlation between gender and greywater discharge while the number of occupants' factor shows a not statistically significant outcome ($r = −0.195$; $p = 0.675$). Furthermore, the results for the drainage within a distance of 21–40 m, 6–80 m, and 81–100 m, display a strong but negative partial correlation between gender and greywater discharge for the number of occupants' factor. The correlation coefficient and the p values for 21–40 m, 61–80 m, and 81–100 m is ($r = 0.837$, $p = 0.019$), ($r = −0.684$, $p = 0.090$), and ($r = 0.977$, $p = 0.100$), respectively. Based on the analysis, less separation of gender category will influence the greywater discharged in high volume indicated by the negative sign of the partial correlations. However, the potential for the ditches to be in polluted condition depends on the significant value. In comparison with Table 4, the main sources (bathroom and basin) of 21–40 m, 61–80 m, and 81–100 m drainage distance polluted the ditches.

TABLE 3. The relationship between demographic profile and greywater discharged based on drainage distance (m)

Distance (m)	Demographic Profile-GWD	Partial Correlation, r	Significant, p < 0.05
0–20	Gender Category No of Occupant	−0.547 0.953	0.204 0.001
21–40	Gender Category No of Occupant	−0.837 0.909	0.019 0.005
41–60	Gender Category No of Occupant	−0.195 0.465	0.675 0.293
81–100	Gender Category No of Occupant	−0.684 0.966	0.090 0.000
0–100	Gender Category No of Occupant	−0.977 0.819	0.000 0.024

The pollution of ditches was mainly due to the household activities and the category of gender, which was the factors that influenced the greywater discharge. For the number of occupants, greywater discharge was observed to have a high positive correlation. Positively correlated means the increase in the number of occupants will lead to a higher volume of greywater discharged. This may result in higher possibility of the ditches to be polluted. It was generally observed that most of the drainage distances have a strong correlation except distance 41–60 m, which was moderate although the potential pollution threat for the ditches still remained high. The significant value obtained from the statistical analysis illustrated that the contributing factors were below 0.05, excluding the drainage distance of 41–60 m. This result means that the two variables were dependent on each other and the it will cause in the pollution of the ditches when the greywater is discharged untreated. Meanwhile, the overall statistical data analysis (t-test and partial correlations) above can be summarized and concluded that the household activities and a variable number of occupants contributed significantly to the greywater discharge. Investigation revealed that both factors have strong relationships but gender category will not necessarily affect the condition of ditches as a result of pollution. Moreover, the less gender category will result in higher greywater discharged.

TABLE 4. The household greywater qualities of three different range of drainage distance

Parameter	Distance			1974 EQA, 2009 Regulations	
	Low	Medium	High	Standard A[a]	Standard B[b]
pH	5.88	6.30	5.68	6.0– 9.0	5.5–9.0
Turbidity – NTU	41.7	10.30	43.80	NA	NA
BOD_5 - mg/l	333.83	173. 63	161.69	20	50
COD – mg/L	320.00	760.00	640.00	120	200

Note:
Distance – low, medium, high – 0–20 m, 41–60 m, 81–100 m respectively
BOD5—five-day biochemical oxygen demand, COD—chemical oxygen demand,
EQA—Environmental Quality Act of Malaysia, NA—not applicable, SD—standard deviation,
[a]For disposal upstream of drains
[b]For disposal downstream of drains

GREYWATER TREATMENT EFFICIENCY BY USING POTTERY WASTE CERAMIC FILTER (PWCF)

The experimental analysis of the physio-chemical parameters of the greywater was conducted to investigate the effect of the treatment efficiency of the PWCF using different particle sizes (0.25, 0.60 and 1.18mm) at different HRT (1, 2 and 3 hours). The average raw greywater concentration was examined before the treatment process. The result showed that the particle size for each operating condition has no effect on the reduction of TSS at 1 h HRT. It was observed that 80.23% removal efficiency was achieved irrespective of the ceramic particle size although the optimum removal efficiency was achieved at 3 h HRT. The pH of the treated greywater determines the suitability of the treated effluent to discharge. The pH slightly increased for each treatment process with the optimum pH was achieved at 0.60 mm for each HRT. Each treatment process at optimum particle size achieved the optimum pH at 2h HRT. Similarly, the investigation revealed that for each treatment system, the pH reduced at 3 h HRT for each particle size. The pH ranged from 6.14 to 6.65 for all operating conditions. These values were within the permissible discharge limit according to the Malaysia Environmental Act 1974 (Al-Mamum, 2013). The values were also within the discharge standard limit set by the Australia-Environment Act, 2002 (Pannel, 2010). This is evident that pH was not a violated parameter in the greywater characteristics. The reduction of COD was high at 3 h HRT (Tables 5 and 6) with 99.37 and 99.79% removal efficiency, respectively. Furthermore, optimum reduction of COD was achieved using 0.60 mm particle size at 2 h HRT (Table 7).

TABLE 5. The greywater characteristics (mg/L) for pottery waste ceramic filter (PWCF) size 0.25mm

Parameters	Ceramic Size	Average Raw Greywater	HRT 1	HRT 2	HRT 3
			% Removal	% Removal	% Removal
BOD	0.25	107.40	67.88	67.90	74.30
COD	0.25	473	86.47	90.90	99.37
pH	0.25	5.98	6.42	6.5	6.18
TSS	0.25	1.67	80.23	88.5	100.00
Chloride	0.25	108	11.79	17.9	0
Bromide	0.25	0.2328	0	8.2	36.37
Sulphate	0.25	544	9.72	8.75	0

The concentration of chloride, bromide and sulphate achieved indicated lower removal efficiency at different particle size of the PWCF. This observable trend implies that the PWCF was not effective for the removal of chloride, bromide and sulphate. Wei et al. (2011), observed on low efficiency of the treatment system for the treatment of bromide ion. The authors clamied that this was attributed to more bromide ions migrate to the compartment as a result of the concentration gradient leading to an increase in the osmotic pressure in the chamber. This caused depletion of OH^- and H^+ in the system. It was also observed that the physio-chemical parameters of the greywater including BOD, COD and TSS reduced better at low particle size. This revealed that the efficiency of the PWCF for the reduction of the considered physio-chemical parameters of the household greywater is more favourable at lower working particle size. Bonvin (2016) also reported that the removal of micropollutants in the aqueous phase is more effective at smaller particle sizes. The authors illustrated that 1 μm particle size was more effective in the removal of micropollutants in the wastewater compared to other working particle sizes used in the investigation. The removal of cations was found to achieve better removal using small particle size (Polletini et al. 2016).

TABLE 6. The greywater characteristics (mg/L) for Pottery waste ceramic filter (PWCF) size 0.60 mm

Parameters	Ceramic Size	Average Raw Greywater	HRT 1	HRT 2	HRT 3
			% Removal	% Removal	% Removal
BOD	0.60	107.40	48.04	67.60	41.90
COD	0.60	473	96.41	95.35	99.58
pH	0.60	5.98	6.32	6.62	6.30
TSS	0.60	1.67	80.23	20.36	76.4
Chloride	0.60	108	6.91	8.14	8.49
Bromide	0.60	0.2328	19.26	50.90	0.00
Sulphate	0.60	544	0.14	4.25	2.46

TABLE 7. The greywater characteristics (mg/L) for pottery waste ceramic filter (PWCF) size 1.18 mm

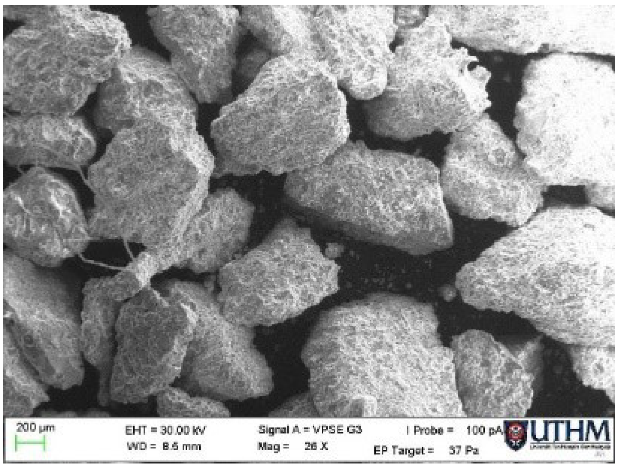
Parameters	Ceramic Size	Average Raw Greywater	HRT 1	HRT 2	HRT 3
			% Removal	% Removal	% Removal
BOD	1.18	107.40	41.34	63.12	77.09
COD	1.18	473	67.02	99.79	96.82
pH	1.18	5.98	6.27	6.29	6.14
TSS	1.18	1.67	80.23	71.26	59.88
Chloride	1.18	108	8.76	0	3.80
Bromide	1.18	0.2328	46.95	0	2.19
Sulphate	1.18	544	0.00	0	7.46

TABLE 7. The greywater characteristics (mg/L) for pottery waste ceramic filter (PWCF) size 1.18 mm

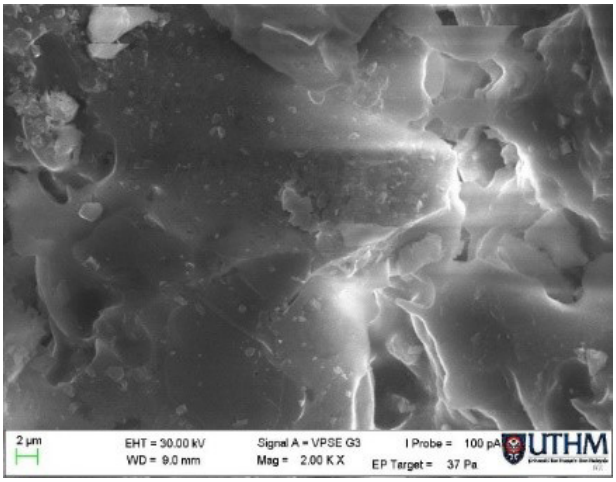
Parameters	Ceramic Size	Average Raw Greywater	HRT 1	HRT 2	HRT 3
			% Removal	% Removal	% Removal
BOD	1.18	107.40	41.34	63.12	77.09
COD	1.18	473	67.02	99.79	96.82
pH	1.18	5.98	6.27	6.29	6.14
TSS	1.18	1.67	80.23	71.26	59.88
Chloride	1.18	108	8.76	0	3.80
Bromide	1.18	0.2328	46.95	0	2.19
Sulphate	1.18	544	0.00	0	7.46

SURFACE MORPHOLOGY OF THE POTTERY WASTE CERAMIC FILTER (PWCF)

The morphology of the PWCF was obtained at 0.25 mm particle size. This was investigated using the detection from the backscatter electrons in the secondary beams to obtain the SEM images. Figure 8a represents the surface morphology of the optimum PWCF particle size. The surface shown as coarse and rough before the treatment process, indicating that the rough surfaces have the tendency to provide active sites for the attachment of organic in the greywater sample. In contrast, Figure 4 illustrates the image obtained after the treatment of greywater before being discharged. It was observed that the surface of the particle size in Figure 8b was very smooth with no evidence of major cracks on the surface of the particle. This could be the result of particle dispersion in the treatment chamber and the dissolution of the particles in contact with the greywater sample in the PWCF. This could influence the mass transfer of the solutes as a result of pore diffusion in the available sites on the ceramic surface.



(a)



(b)

FIGURE 4a,b. The morphology of the pottery waste ceramic filter (PWCF) particle size before and after treatment

CRYSTALLINITY OF THE PWCF

The XRD analysis revealed that quartz, siliminite and mullite were the major compounds in the sampled filter media. It was observed that the $SiO2$ and $Al2O3$ were the major compounds that formed the filter media. XRD pattern of the compound illustrated in Figure 5 had crystalline structure consisting of chemical compounds, containing 53% $SiO2$ (quartz) and 26% mullite ($3Al2O3.2SiO2$) in the PWCF media (Figure 5a). This finding is similar to Quin et al. (2015). Siliminite ($Al2SiO5$) and phosphorus (P) are categorised as other compounds present in the sample with a composition of 15 and 6%, respectively.

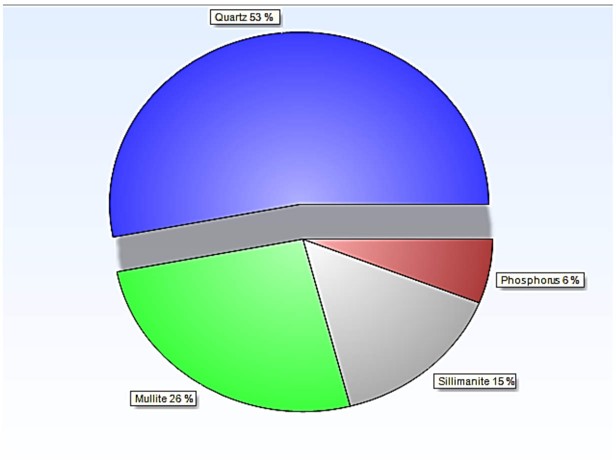


FIGURE 5a. The mineral composition of pottery waste ceramic filter (PWCF)

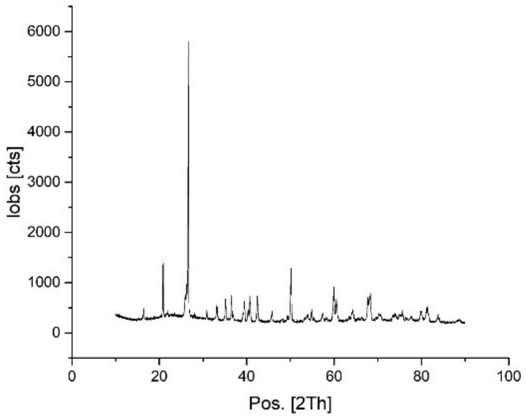


FIGURE 5b. The X-ray diffraction pattern of pottery waste ceramic filter (PWCF)

The crystalline phase on the XRD of the filter media is illustrated in Figure 5b. It shows that quartz is the major compound that forms the filter media (Purohit et al. 2016). Materials, predominantly quartz has been applied as a filter media for the treatment of effluent before being discharged (Hu et al. 2017). In the treatment of greywater using bed reactor, quartz was used as filter media, the purification capacity of the reactor was investigated using 60L of greywater sample. Results showed that the media effectively reduced pathogenic bacteria, TSS from 27.3 mg/L to 7 mg/L, and also COD from 21.2–4.2 mg/L (Rakovitsky et al. 2016).

CHEMICAL COMPOSITION OF THE POTTERY WASTE CERAMIC FILTER (PWCF)

The chemical composition by weight of the filter media from EDX is presented in Figure 6. The major elements with spectra show the significant chemical elements in the filtration system for the treatment of the household greywater. The mass composition of the contributing elements is presented in Table 8. The EDX spectrum at 0.525 kV, 1.486 kV, and 1.739 kV shown in Figure 10 was dominated by the presence of oxygen, silicon and aluminium. There was a noticeable spectrum at 6.398 kV comprising of 2.51% of Fe. The findings were consistent with the composition of the major compound (quartz) in the XRD analysis. It is reported that Al-Si in the ceramic enhances the porosity of the filter media in the treatment system (Samuel et al. 2016). However, the dominating elements of Al-Si in the filter media in PWCF provide active sites for attachment of the investigated parameters on the surface of the filter media.

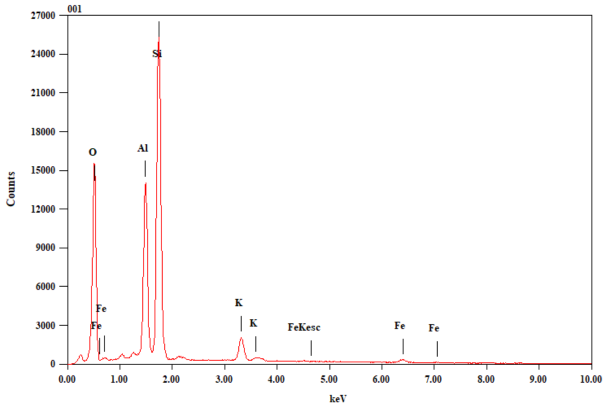


FIGURE 6. The elemental composition of pottery waste ceramic Filter (PWCF)

From the spectra, O, Si and Al are the major element contained in the filter media.

TABLE 8 The mass composition of elements

Element	KeV	Mass %	Error %	At%
O	0.525	40.75	0.14	55.57
Al	1.486	15.85	0.11	12.82
Si	1.739	35.76	0.13	27.77
K	3.312	5.13	0.23	2.86
Fe	6.398	2.51	0.78	0.98
Total		100.00		100.00

CONCLUSION

The results revealed that a distance within 81–100 m was significant to the influence of gender and the number of household occupants of the greywater discharged. It was observed that the mean reduction of COD at 99.37%, BOD 74.3%, and TSS 100% were optimum using 0.25 mm particle size at 3 h HRT. However, the PWCF was not effective for the treatment of Cl and sulphate under the operating conditions used for the study. This implies that the PWCF can be used as viable option to reduce pollution load from greywater discharged into water body.

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DECLARATION OF COMPETING INTEREST

None

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