International Journal of Engineering & Technology, 7 (3.9) (2018) 11-14

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Calculation of Filter Lifetime Using Empirical Model Applied to Hydrodynamic Column for Phosphate Removal from Greywater

Mohd Hairul Khamidun[1]*, Umi Fazara Md Ali[2], Shakila Abdullah[3]

[1]Micropollutant Research Centre, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat.
[2]School of Environmental Engineering, University Malaysia Perlis, Kompleks Pusat Pengajian Jejawi 3, 02600 Arau, Perlis, Malaysia;
[3]Faculty of Applied Sciences and Technology, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat
**Corresponding author email: hairulk@uthm.edu.my*

Abstract

Greywater is one of the point source pollution that negatively impact water resources if not properly treated. However, improvement of greywater quality can be potentially used for irrigation purpose. The main objective of this study is to calculate the lifetime for calcined waste mussel shell (CWMS) in hydrodynamic column. This study was performed using laboratory scale hydrodynamic column filled with CWMS to determine the breakthrough curve, adsorption capacity, accumulation rate and lifetime using empirical model for the adsorption of PO_4^{-3} onto CWMS from greywater. The bed height and flow rate that used in the experiment are 200 mm and 80 mL/h, respectively. The results demonstrate that breakthrough and exhaustion times are 12h and 18h, respectively. The empirical model was verified using experimental equilibrium data. The values of k_1 and q_{max} calculated using model equations are 0.122 mg/g h^2 and 0.0017 mg/g, respectively. On the basis of the results, CWMS can be economically basis media used as an adsorbent for the removal of PO_4^{-3} from greywater in the hydrodynamic column.

Keywords: *Adsorption; Calcined waste mussel shell; Empirical model; Greywater*

1. Introduction

The water quality status of water bodies in Malaysia has always been a cause for concern for various local authorities, government agencies as well as the public at large. One of the sources pollutions into the water bodies is greywater. Greywater can be considered washing water from bathtubs, showers, bathroom wash basins, clothes washing machines and laundry tubs, kitchen sinks and dishwashers. Greywater usually contains soap, grease, food particles, household chemicals, textile fibres, skin particles, hair, dirt, and other bacteria [1]. Greywater is classified into two types: light greywater and dark greywater. Light greywater is wastewater from the bathroom and wash basin. Dark greywater is wastewater from kitchen sinks and laundry [2].

Eriksson et al. [3] reviewed that the greywater composition of pollutants has wide range of concentration i.e. COD 13-1380 mg/L; BOD 90–676 mg/L; SS 54-720 mg/L; turbidity 14-296 NTU: total nitrogen 0.6–74 mg/L and total phosphorus 4–14 mg/L. High concentrations of these pollutants from greywater discharging into water bodies have deteriorated water quality of water resources. The excessive concentration of phosphorus may run-off or leach through the soil to enter waterways and aquifers, resulting in algal blooms.

Many types of treatment systems have been introduced to improve greywater quality. The typical flow of greywater treatment system starts with screening process and followed by sedimentation process. Subsequently, the greywater through the main treatment process i.e physical, chemical, biological or extensive treatment system. Typical physical methods for greywater treatment are membrane and sand filter. Coagulation, electro-coagulant and photo-catalyst are common chemical methods. For biological method, sequencing batch reactors, aerated bio-reactors, rotary biological contactors and biological aerated filter are some of the common treatment systems [4]. An investigation was made by Ramprasad et al. [5] on greywater from the student residential hostel using Green Roof-Top Water Recycling System. The hydraulic loading rate and retention time are 53.1 – 58.9 m^3/day and 0.7 – 1.3 day, respectively. Influent of PO_4^{-3} 2.9–3.8 mg/L was reduced to 0.8–1.4 mg/L (removal 87.9%). However the main disadvantage of constructed wetland required a large area.

Multi filtration studies through sandstone, rocks aggregates, zeolite, diatomite and activated carbon were conducted on greywater from showers and washing sinks [6]. The system gives promising result for removal BOD, COD, and TSS was about 88, 83, and 92%, respectively. Removal of total phosphorus was only 32.5%, meaning that the selection of filtration media in the system should be relevant for selected removal pollutant. Even though many studies have conducted to treat greywater, the use of mathematical models to find out the lifetime of filter still not fully understand.

Adsorption is a physicochemical process and widely used in many studies due to freely available, have good capacity uptake and require less treatment. The used of low cost adsorbent such as an abandoned waste generated from agricultural and fishery industries are nowadays receiving attention of many researchers. Re-

Copyright © 2018 Authors. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

utilization of these waste materials needs to be expanded to reduce waste volume [7, 8]. In this study, the waste mussel shell was used as an adsorbent. The continuous bed process (column) in the laboratory is one of the most important aspects in development and optimization of adsorption parameters. The objective of this study is to use the mathematical models to calculate the accumulation rate and lifetime for the adsorption PO_4^{-3} onto calcined waste mussel shell (CWMS) from greywater

2. Materials and Methods

2.1. Preparation of Calcined Waste Mussel Shell

Waste mussel shells were collected from the local restaurant in Batu Pahat, Johor. The shells were repeatedly washed and scrubbed several times with tap water to remove impurities and then were dried in oven at 105 ^oC for 24 h. The shells were crushed and sieved to 0.8 – 1.18 mm particles sizes and then calcined at 700 ^oC for 2 h. (Jones et al., 2011). The calcined waste mussel shells (120g) were used to investigate the removal of pollutants from greywater in the hydrodynamic column.

2.2. Greywater Sampling and Characteristics

The light greywater used for hydrodynamic column experiments in this study was collected from the bathroom of single unit residence house in Batu Pahat. The raw light greywater samples were collected from the end point of bathroom drainage system as 5 L grab samples in air tight plastic bottles. For the physic-chemical analysis of collected greywater samples including pH, dissolve oxygen (DO), suspended solid (SS), chemical oxygen demand (COD), PO_4^{3-}, NH_4^+ and turbidity. The parameters of TSS, pH, DO and turbidity were measured using gravimetric method, Eutech pH700 meter, YSI DO meter, and HACH 2100P turbidity meter, respectively. The concentrations of COD, NH_4^+, and PO_4^{3-} were analysed by reactor digestion, Nesslerization, and Amino Acid methods using HACH DR6000 UV–Vis Spectrophotometer, respectively

2.3. Hydrodynamic Column Experiment

Hydrodynamic column experiment were performed in acrylic mini column with an inner diameter of 15 mm and a height of 250 mm. The layout of the hydrodynamic column as shown in Figure 1. The untreated greywater's gravitational flow through the packed columns (bed depth of 200 mm) at constant flow rate of 80 mL/h. The concentration of PO_4^{3-} was monitored at inlet and outlet of the hydrodynamic column.

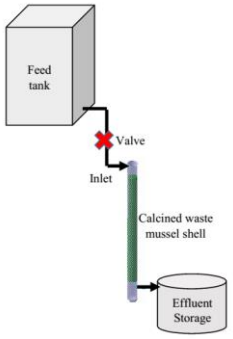


Fig.1: Schematic diagram of continuous hydrodynamic column system.

2.4. Empirical Model

The empirical model developed by [10] can be used to calculate accumulation rate and lifetime of adsorbate onto adsorbent based the time rate of change $q'(t) = dq/dt$ is proportional to $q(t)$. The plot of accumulated adsorbate (mg/g), q_{acc} against accumulation time (h), t yield the hyperbolic first order is represent by equation (1)

$$q_{acc} = q_{max} - q_{max}\,(e^{-k1t}) \quad (1)$$

The equation (1) can be rearranged in linear form using Thomas graphical method as shown in equation (2)

$$(t/q_{acc})^{1/3} = (k_1^{2/3}/6q_{max}^{1/3})t + (1/\,k_1\,q_{max})^{1/3} \quad (2)$$

An analogous of the equation (2) to $y = s\,x + C$, where s is defined as slope and C is interception of curve $(t/\,q_{acc})^{1/3}$ againts t, x-axis is t and y-axis is $(t/q_{acc})^{1/3}$. Thus k_1 is constant and is expressed by the following equation

$$k_1 = 6\,(s/C) \quad (3)$$

The accumulation rate coefficient (k_1) can be calculated to use equation (2) since the s and parameter C have been verified on a linear plot of $(t/\,q_{acc})^{1/3}$ againts t.

Equation (4) can be used to determine ultimate adsorption capacity (q_{max}) since the values of the parameters (s;C) were verified as for the calculation of k_1 in. It is defined as maximum quantity of adsorbate adsorb onto adsorbent and is constant.

$$q_{max} = 1/\,(6sC^2) \quad (4)$$

3. Results and Discussions

3.1. Characteristic of Greywater

The greywater characteristics obtained in this study was compared to Environmental Quality (Sewage) Regulations 2009 (Standard B) as shown in Table 1. The concentrations COD and DO are exceeded the Standard B. The concentration of PO_4^{3-} is 13.8 mg/L is higher and suffices to accelerate eutrophication in waters [11]. Thus, this study was used hydrodynamic column filled with CSMS attempted to remove PO_4^{3-} from greywater.

Table 1: Characteristic of greywater

Parameter	unit	Greywater	Standard B
COD	mg/L	340	200
PO_4^{3-}	mg/L	13.8	10
DO	mg/l	1.71	5-7
SS	mg/L	24	100
Turbidity	NTU	76	N/A
NH_4^+	mg/L	3.85	10
pH	-	6.73	5.5-9.0

3.2. Hydrodynamic Column Analysis

In this study, the removal of PO_4^{3-} from greywater in hydrodynamic column was monitored to determine the breakthrough curve, adsorption capacity, accumulation rate and lifetime of adsorbent using empirical models. Figure 2 shows breakthrough curve for hydrodynamic study by plotting the ratio of PO_4^{3-} influent concentration to PO_4^{3-} effluent concentration versus time. The curve shows that breakthrough time occurred when C_i/C_o is 0.4 at 12 h and the exhaustion time at 18 h. Before breakthrough occurred more free active sites on the surface of CSMS may have a high capability to adsorb PO_4^{3-} ions from greywater [12]. When it reached exhaustion time, the rate of PO_4^{3-} adsorption is slow because of a number of active sites have been covered by PO_4^{3-} [13]; the adsorption equilibrium can be then achieved after 18 h.

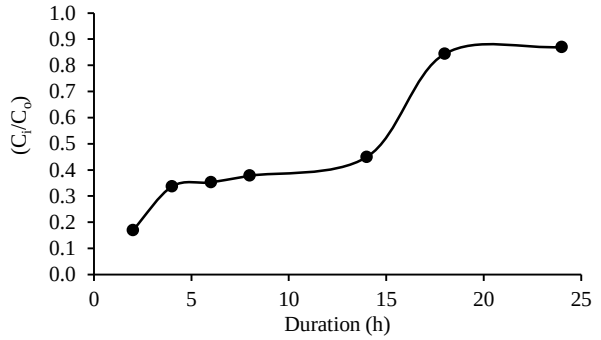


Fig.2: The experimental breakthrough curves for the adsorption of PO_4^{3-} onto CWMS at bed depth of 200 mm and flow rate of 80 mL/h

3.3. Empirical Models Calculation

The model used in this study is empirical approach to graph straight line. For experimental data obtained from hydrodynamic column study, a plot of $(t/ q_{acc})^{1/3}$ againts t in equation (2) yielding a linear curve as shown in Figure 3. The values of s and C from a linear curve are 0.3429 and 16.868, respectively. Correlation for the linear graph is very good (R^2> 0.97) indicating that the use of the model could be useful for determining k_1 and q_{max}. Using equation (3) permit us to calculate k_1 which is equal to 0.122 mg/g h^2 and using equation (4) to calculate q_{max} for CSMS to adsorb PO_4^{3-} from greywater. The calculated q_{max} in this study is 0.0017 mg/g. The lifetime for CSMS used in the hydrodynamic column was calculated to be 14.5 h by using equation (1). This result interprets that lifetime for CSMS to reach the maximum of PO_4^{3-} removal from greywater is 14.5 h of contact time. Over the CSMS's lifetime, the adsorption capacity decreases as the PO_4^{3-} sites become saturated.

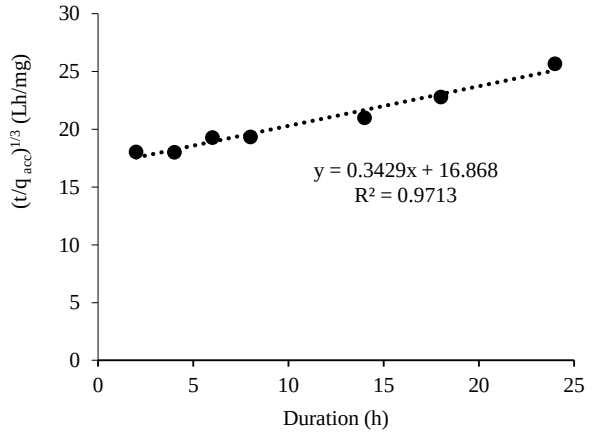


Fig.3 Results of the linear regression analysis for the calculation of k_1 and q_{max}

Error analysis was carried out to test the adequacy and accuracy of the model equations. The average percentage errors (ε in %), indicating the differences between the experimental and theoretical values of q_{acc}, were calculated as following equation [14]

$$\varepsilon = \Sigma_1^n [((q_{acc})\text{exp} - (q_{acc})\text{theo}))/ (q_{acc})\text{exp}]/n \times 100 \quad (5)$$

where n is the number of measurements

Figure 4 shows the experimental data and theoretical curves obtained from the empirical model. As shown in figure accumulation adsorbate obtained by experimental is in good agreement with predicted by empirical model. Besides, the correlation coefficient is more than 0.9 and the percentage errors is 1.4%. Thus, this result is sufficiently accurate to permit the control of adsorption of PO_4^{3-} onto CSMS from greywater in laboratory scale hydrodynamic column.

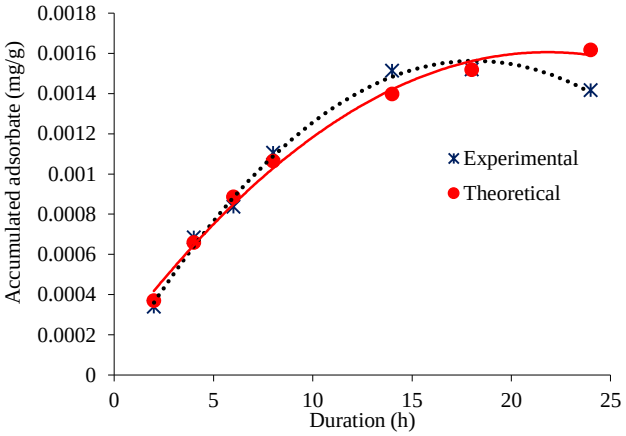


Fig.4: Curve of plotting q_{acc} versus t for experimental data and theoretical.

4. Conclusion

This study used the empirical models for adsorption of PO_4^{3-} from greywater onto CWMS in hydrodynamic column. Breakthrough curve shows that the performance of the CWSM to remove PO_4^{3-} from greywater is good. The breakthrough and exhaustion times are 12 and 18 h, respectively. The empirical model was used for calculating the adsorption capacity, accumulation rate and lifetime of CWMS to adsorb PO_4^{3-} from greywater. All the parameter in the empirical model has physical meaning, higher value of R^2 and lower value of ε showed the model remained accurate. A method to determine lifetime of CWMS in hydrodynamic column related to accumulated adsorbate is verified to contribute to the water quality improvement analysis and estimation time for replacement reactive filter.

Acknowledgement

The authors gratefully acknowledge financial support from the Universiti Tun Hussien Onn Malaysia for the Short Term Grant: Vot. U635

References

[1] Beler-Baykal B (2014) Stream Segregation in Household Use: A Review of Grey Water as an Alternative Source of Water and Yellow Water as an Alternative Source of Fertilizers. Water Qual Expo Heal 7:27–37.

[2] Ghaitidak DM, Yadav KD (2013) Characteristics and treatment of greywater-a review. Environ Sci Pollut Res 20:2795–2809.

[3] Eriksson E, Auffarth K, Henze M, Ledin A (2002) Characteristics of grey wastewater. Urban Water 4:85–104.

[4] Siang K, Yip J, Leong C, et al (2018) A review of greywater recycling related issues : Challenges and future prospects in Malaysia. J Clean Prod 171:17–29.

[5] Ramprasad C, Shirley C, Memon FA, Philip L (2017) Removal of chemical and microbial contaminants from greywater using a novel constructed wetland : GROW. Ecol Eng 106:55–65.

[6] Ghrair AM, Al-Mashaqbeh OA, Megdal SB (2015) Performance of a Grey Water Pilot Plant Using a Multi-Layer Filter for Agricultural Purposes in the Jordan Valley. CLEAN - Soil, Air, Water 43:313–462.

[7] Othman N, Kueh YS, Hamdan R (2014) Watermelon rind : A Potential Adsorbent for zinc removal. Appl Mech Mater 680:146–149.

[8] Khamidun MH, Fulazzaky MA, Md Din MF, Mohd Yusoff AR (2014) Resistance of mass transfer , kinetic and isotherm study of ammonium removal by using a Hybrid Plug-Flow Column Reactor (HPFCR). In: Sung W-P, Kao Jimmy CM, Chen Ran (eds) Proceedings of the 2013 International Conference on Frontier of Ener-

gy and Environment Engineering, ICFEEE 2013. Taylor & Francis Group, Xiam, pp 555–559

[9] Jones MI, Wang LY, Abeynaike A, Patterson DA (2011) Utilisation of waste material for environmental applications: calcination of mussel shells for waste water treatment. Adv Appl Ceram 110:280–286.

[10] Fulazzaky MA, Omar R (2012) Removal of oil and grease contamination from stream water using the granular activated carbon block filter. Clean Technol Environ Policy 14:965–971.

[11] Weiner RF, Matthews RA (2003) Water Pollution. In: Environmental Engineering, 4th edn. Elsevier Science, Burlington MA, pp 51–79

[12] [12] Khamidun MH, Abdul Rahman MA (2017) Analysis of Mass Transfer Resistance for Adsorption of Phosphate onto Industrial Waste Materials in Plug-flow column. In: MATEC Web of Conferences.

[13] Yu Y, Chen N, Wang D, et al (2017) Adsorption of Phosphorus Based on Hangjin Clay Granular Ceramic from Aqueous Solution and Sewage : Fixed-Bed Column Study. Environ Prog Sustain Energy 36: 1323-1332.

[14] Chen Y-S, Chang W-C, Chuang S-H, Chiang S-M (2011) Comparison of kinetic models for predicting phosphate adsorption onto spent alum sludge in a continuous fixed-bed column. Desalin Water Treat 32:138–144.