ESTIMATION OF REACTION RATE CONSTANTS OF POLLUTANT REMOVAL FOR SUBSURFACE FLOW CONSTRUCTED WETLANDS TREATING GREY WATER

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***ABSTRACT*:** Treatment efficiencies of a pilot scale constructed wetland to treat greywater from a staff canteen of the University of Moratuwa was studied to estimate the temperature dependent reaction rate constants of specific pollutant removal mechanisms. The treatment cell, constructed below the ground level is four meter (4.0 m) long 1.8 m wide (at the top level). The cell is divided longitudinally at the center while vertical baffles are provided at approximately 590 mm intervals, running through the entire vertical depth (0.75 m) of the wetland cell with an opening of 270 – 380 mm. Considering the middle separation, the effective average width and the length of the treatment cell is 0.75 m and 8.0 m, respectively. The effective volume of the cell is approximately 4000 l considering a porosity of 0.5 for the substrate. The bed is vegetated with cat tail (Typha Latifolia) planted at approximately 0.75 m intervals. The study estimates the design parameters pertaining to local conditions to optimize the design considerations and sizing requirements using both first order and Monod type models. The estimated parameters can effectively be applied in sizing constructed wetlands in tropical climatic conditions. The results show that the surface area of subsurface flow constructed wetlands can be reduced by a considerable percentage by utilizing the newly estimated parameters from the current study.

KEYWORDS: BOD_5, COD, First order kinetics, Nutrients

1. INTRODUCTION

Wynn and Liehr (2001) developed a mechanistic compartmental simulation to model and predict seasonal trends in the removal efficiencies of HFCWs. Korkusuz *et al*. (2004) has presented a methodology and a statistical analysis for the estimation of treatment efficiencies of the constructed wetlands for domestic wastewater treatment.

Vymazal (2005) has provided a very important discussion on subsurface horizontal flow and hybrid constructed wetlands is made including the pollutant removal mechanisms and their efficiencies with experimental results. Since the experimental data and analyses are based on the temperate continental climate conditions, there is a least or no possibility to make a direct relationship with the local conditions when applicable to another place of the world.

Langergraber (2008) has made a review on mechanistic models for subsurface flow constructed wetlands. Wenner and Kadlec (2000) and Chzarenec *et al.* (2003) modeled wetland residence time distributions in temperate climes. Garcia *et al.* (2004), Maloszewski *et al*. (2006), and Schwager and Boller (1997) used tracer experiments to determine hydraulic parameters with different filter materials.

Therefore it is evident that very limited research works have been carried out focusing on parameter estimation and optimization of SF constructed wetland systems over the Europe and the United States. However in Sri Lanka, the acceptance of, constructed wetlands as an efficient and cost effective wastewater treatment method is very limited. This may be especially due to the scarcity of the land due to high population density as well as the insufficient research work on constructed wetlands, specifically under the local conditions. Therefore, it is an essential requirement to estimate both design and operational parameters of the constructed wetland under the specific climatic and environmental conditions in the country.

1.1 Objectives

The present study was carried out to estimate the temperature dependent reaction rate constants of specific pollutant removal mechanisms of a subsurface horizontal flow constructed wetland (SSHF CW) treating greywater which can be used in the preparation of wetland sizing guide lines.

2. METHODOLOGY

The system consists of two settling tanks with a grease trap for the pre-treatment. The pre-treated water entered into the wetland cell through a perforated pipe and both inlet and outlet partitions are filled with 40 mm gravel. The water passes through a 20mm gravel bed inside the wetland cell. Wetland cell maintains a bed slope of 1% with the planted aquatic species broad leaved cattail *(Typha latifolia).*

Table 1 shows the characteristics of the pilot scale subsurface flow constructed wetland (fed with grey water discharged from a staff canteen at university of Moratuwa) used for the study. The original design flow rate of the SSHF CW was only 0.5 m^3/day, however, due to the change of usage pattern over the last two years, it was modified up to the current level of 1.428 m^3/day, thus reducing the designed retention time from 6 days to 2 days.

Table 1. Characteristics of the pilot scale subsurface flow constructed wetland at university of Moratuwa.

Parameter	value
Q – flow rate	1.428 m^3/day
Φ – porosity	0.435
d – depth	0.75 m
L -length	4.00 m
W – width	2.16 m
V_e – effective volume	2.643 m^3
A – surface area	8.64 m^2

2.1 Sample collection and analysis

Samples from inlet and outlet of the SSHF constructed wetland were collected on 1-2 week time intervals and analysed for pH, Temperature, Turbidity, Conductivity, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Nitrate Nitrogen, Nitrite Nitrogen, Total Phosphorous, Total Coliforms and Suspended Solids. Sample collection will be continued up to November 2011.

2.2 Estimation of reaction rate constants

In order to derive an equation that represents the internal metabolisms of pollutant removal of the SSHF constructed wetland, the general terms of mass conservation of a plug flow system was used while keeping the first order kinetics model as a basis.

According to mass conservation;

In = Out + Assimilation+losses

Assuming zero losses considering the smaller size of the wetland (low evapotranspiration) and complete lining;

$$C_i = C_e + C_a$$

$C_a = C_i - C_e$ ……………………………………… (a)

Where;

C_i – influent concentration of a single pollutant (C_a – assimilated concentration of a single pollutant (mg/l)

Assuming first order kinetics prevail,

$(C_e / C_i) = e^{-K_T t}$,

the following relationship is obtained by substituting in equation (a);

$C_a = C_e \{(1- e^{-K_T t}) / e^{-K_T t}\}$ ………………………..….. (b)

Where;

K_T – temperature dependent reaction rate constant

t – retention time

C_e – effluent concentration of a single pollutant (mg/l)

Then differentiate the equation (b) w.r.t. K_T, which is the reaction rate constant in relation to a particular pollutant.

$d(C_a)/ d(K_T) = d(C_e)/ d(K_T) \{(1- e^{-K_T t}) / e^{-K_T t}\} + C_e \{t.e^{K_T t}\}$ …. ……………………………………(c)

simplifying;

$d(C_e)/ d(K_T) = - tC_e$ ………………………….... (d)

2.3 Effective sizing of the constructed wetland

The estimated reaction rate constant for each parameter can then be used to build a relationship between the retention time and effluent concentration of treated greywater. For that, the equation (b) is differentiated w.r.t. retention time (t) and thereby, the equation (e) is derived. Although, the equations (d) and (e) seem to be same in mathematical formulation, their application is quite different. In the equation (e), K_T is not a constant for every case of study and it only remains constant for a particular parameter as estimated previously.

$d(C_e)/d(t)=-K_T C_e$…………………………….... (e)

Then, the equations (d) and (e) were solved by *Runge Kutta (RK_4)* method. For each individual pollutant, an optimum t value is obtained using the *dessolver 1.7* and, the maximum value is taken as the system's retention time that would enable the optimal of treatment.

Then, the surface area is recalculated as follows.

$Q = V/t_{max}$ ………………….................................... (f)

$Q = A.d/t_{max}$

$A = Q.t_{max} /d$ ………………….............................. (g)

The retention time should be selected in accordance with the required treatment level of treated water Thus, the constructed wetland can be effectively sized.

3.0 RESULTS

Table 2. Estimation of reaction rate constants (K_T)

Parameter	Temperature dependant reaction rate constant – K_T (day^{-1})±SE
BOD_5	0.7564±0.012
COD	0.5609±0.011
Nitrate Nitrogen	0.3921±0.003
Nitrite Nitrogen	0.7867±0.001
Total Kjeldhal Nitrogen	0.2459±0.014
Total Phosphorous	0.3993±0.078
Total Suspended Solids	0.2586±0.022
Total Coliforms	0.6314±0.012

The estimation of the reaction rate constants for each parameter were calculated using the measured data at the inlet and the outlet of the wetland cell based on the equations (a) to (d) using the differential equation solving software *dessolver 1.7*. Table 2 shows the reaction rate constants for different parameters of the SSHF CW.

The optimum retention time that would yield the minimum required treatment level, based on SL standards was calculated by using the measured data and the estimated reaction rate constants based on the equation (e).

Generally, sizing of wetlands treating greywater is performed based on the COD or BOD removal efficiencies. Table 3 shows the calculation of the optimum retention time based on BOD and COD removal efficiencies. Based on this, the optimum retention time for the SSHF CW in consideration, can be taken as 3.3 days. Assuming a retention time of 3.3 days and using equation (g), the surface area of the present pilot scale constructed wetland was recalculated as 6.24 m^2, thus, yielding a reduction of surface area by 28%.

Table 3. Estimation of optimum retention time

Parameter (reference)	Retention time – t (day)
BOD_5 (50 mg/l)	3.2793
COD (250 mg/l)	2.2291

4.0 DISCUSSION

It was observed that very few models have been developed to simulate pollutant removal processes in SFCWs and only a fewer number of models of these are applicable for SSHFCWs (Langergraber, 2008). In fact, many of those models are applicable for a particular climate or a clime where the model has been developed. Such models should be modified before applying for different conditions. By the way, modification of an existing model can be rather difficult and complex than developing a new model in relation with the local conditions. Modeling of pollutant removal mechanisms of a SHFCW in a particular climate and sizing of the wetland systems would be a challenge because, the procedure should be consisted of the formulation of removal processes, the estimation of parameters in the model and the sizing of the system.

It is known that efficiency of waste water treatment depends on the influent water quality, climate conditions as well as substrate type and plants used (Aleksandra et al, 2008). The reaction rate constants yielded in this study were calculated under high loading rates (i. e. three times the original designed). Hence it is important to calculate the reaction rate constants under varied loading rates and compare the same for better accuracy.

5.0 CONCLUSION

The temperature dependant reaction rate constants were estimated for each parameter under the local conditions in Sri Lanka and it was found that the surface area of the wetland model can be reduced from 8.64 m^2 to 6.24 m^2 which is a 28% reduction while maintaining the required level of treatment of greywater.

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