Parameter Estimation of Pollutant Removal for Subsurface Horizontal Flow Constructed Wetlands Treating Greywater

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Abstract: Treatment efficiencies of a pilot scale constructed wetland treating 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 centre 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 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 SHF CWs can be reduced by 26% by utilizing the newly estimated parameters from the current study.

Keywords: BOD_5, COD, First order kinetics, Nutrients

1. Introduction

In the modern world, the scarcity of high quality water which meets the hygienic requirements or industrial regulations for regular usage is increasing at an alarming rate; meanwhile, the water is always being an expensive commodity. Therefore, the demand for treated water is reaching to a level which might not be satisfied with the available resources even in places where there is no physical lack of it. In such situations, the necessity of effective and efficient wastewater treatment and promotion of water reuse would be highly productive. Hence, the use of highly favoured treatment systems such as constructed wetlands which are associated with natural removal mechanisms of pollutants could be successful applications especially in developing countries since, these systems combine low-cost, low-maintenance, simple and reliable operation, and high removal efficiency (Economopoulou and Tsihrintzis, 2003).

As a developing country, in Sri Lanka, constructed wetlands have not yet been identified as a very efficient and cost effective wastewater treatment method especially where the land is highly populated and the space is limited.

Economopoulou and Tsihrintzis (2003) have presented a simple criterion including the guidelines and mathematical models for the preliminary sizing of subsurface horizontal flow constructed wetland (SHF CW) systems. Wynn and Liehr (2001) developed a mechanistic compartmental simulation consisting six

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sub-models and predict seasonal trends in the removal efficiencies of HFCWs. Langergraber (2008) has made a review on mechanistic models for subsurface flow constructed wetlands developed by several authors. Werner and Kadlec (2000) and Chzarenec et al. (2003) modeled wetland residence time distributions in temperate climes.

However in Sri Lanka, the acceptance of constructed wetlands as an efficient and cost effective wastewater treatment method is very limited and need to be promoted where it is applicable.

1.1. Objectives

The present study was carried out to estimate the temperature dependent reaction rate constants of specific pollutant removal mechanisms of a SHF 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). 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 constructed wetland

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 analyzed 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 SHF 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;

$$C_a = C_i - C_e \quad \text{.................................} (1)$$

Where;

C_i, C_e, C_a – influent, effluent and assimilated concentration (mg/l) of a single pollutant respectively

Assuming first order kinetics prevail,

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

The following relationship is obtained by substituting in equation (1);

$C_a = C_e \{(1- e^{-K_T t}) / e^{-K_T t}\}$ .... (2)

Where;

K_T – temperature dependent reaction rate constant

t – retention time

Then differentiate the equation (2) w.r.t. K_T and simplify the equation;

$d(C_e)/ d(K_T) = - tC_e$ .... (3)

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 (2) is differentiated w.r.t. retention time (t) and thereby, the equation (4) is derived. In the equation (4), K_T is not a constant for every case of study and it only remains constant for a particular parameter as estimated previously.

$d(C_e)/d(t) = -K_T C_e$ .... (4)

Then, the equations (3) and (4) were solved by Runge Kutta (RK4) method. For each individual pollutant, an optimum t value is obtained using the *dessolver 1.7*. Then, the surface area is recalculated as follows.

$Q = V/t_{max}$ .... (5)

$A = Q.t_{max} /d$ .... (6)

3. Results

The estimation of the reaction rate constants for each parameter was performed based on the equations (1) to (3) using *dessolver 1.7*.

Table 2 - Estimation of reaction rate constants (KT)

Parameter	Temperature dependant reaction rate constant – K_T (day^{-1})±SD
BOD_5	0.80799 ± 0.070
COD	0.61166 ± 0.062
Nitrate Nitrogen	0.80131 ± 0.024
Nitrite Nitrogen	0.85634 ± 0.010
Total Kjeldhal Nitrogen	0.28327 ± 0.050
Total Phosphorous	0.34343 ± 0.078
Total Suspended Solids	0.38157 ± 0.095

The optimum retention time that would yield the required treatment level was calculated by using the estimated reaction rate constants based on the equation (4). Thus, the minimum retention time required to achieve certain satisfactory levels of treatment varies from 2.1 days to 3.375 days. i.e. minimum retention time of 2.1 days and maximum retention time of 3.375 were obtained respectively for the treatment of COD and Total Suspended Solids. Then, the optimum retention time for the SHF CW in consideration, can be taken as 3.375 days. Assuming a retention time of 3.375 days and using equation (6), the surface area of the pilot scale constructed wetland was recalculated as 6.426 m^2, thus, yielding a reduction of surface area by 26%.

4. Discussion

Amongst very few of the simulation models, many 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. The reaction rate constants yielded in this study were calculated under high loading rates (i. e. three times the original designed) due to irregular patterns of greywater discharge. Therefore, influent water quality was abundant of anomalies which lead to eliminate some of the data sets. In fact, those data did not meet the satisfactory levels of treatment. Hence it is important to calculate the reaction rate constants under varied loading rates and compare the same for better accuracy.

The estimations of minimum retention time that would be responsible for specific treatment levels are entirely based on the standard values (i.e. BOD5 - 50 mg/l and COD - 250 mg/l) and treatment efficiencies. Thus, a retention time of 3.5 days for the treatment of nitrate nitrogen has been estimated as it results over 90% of removal efficiency; so as the nitrite nitrogen over 90% of efficiency, total kjeldhal nitrogen and total phosphorous over 50% of efficiency and total suspended solids over 60% of efficiency were the bases for respective parameters. Further, it is emphasized that the referred efficiencies for total phosphorous and kjeldhal nitrogen are typical treatment levels of SHF CWs.

5. 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 6.426 m^2 which is a 26% reduction while maintaining the required level of treatment of greywater.

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