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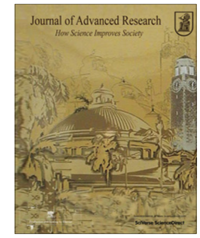
Journal of Advanced Research (2016) xxx, xxx–xxx

Cairo University

Journal of Advanced Research



ORIGINAL ARTICLE

Performance of a vertical subsurface flow constructed wetland under different operational conditions

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ARTICLE INFO

Article history:
Received 2 August 2015
Received in revised form 6 December 2015
Accepted 6 December 2015
Available online xxxx

Keywords:
Constructed wetlands
Vegetation
Sewage effluent
Growth media
Feeding mode
Volumetric rate constant

ABSTRACT

The performance of a vertical subsurface flow constructed wetland (VSSFCW) for sewage effluent treatment was studied in an eight month experiment under different operational conditions including: vegetation (the presence or absence of common reeds "*Phragmites australis*"), media type (gravel or vermiculite), and mode of sewage feeding (continuous or batch). Plants had a significant effect ($P < 0.05$) on the removal efficiency and mass removal rate of all pollutants, except phosphorous. The average removal efficiencies of chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS), ammonium (NH_4) and total-P (TP) were 75%, 84%, 75%, 32% and 22% for the planted beds compared to 29%, 37%, 42%, 26% and 17%, respectively, for the unplanted beds. The VSSFCW was ineffective in removing nitrate (NO_3). The effect of either media type or feeding mode system on the removal efficiency of COD and BOD was insignificant. Vermiculite media significantly ($P < 0.05$) increased the efficiency of the wetland in removing NH_4, TP and dissolved phosphorous (DP) when compared with gravel particularly in the planted beds. The batch mode was more effective in removing TSS and NH_4 compared to the continuous mode. Volumetric rate constant (k_V) was different for various pollutants and significantly increased due to the presence of plants. Media type had no significant effect on the values of k_V for COD, BOD and TSS, while k_V for NH_4 and TP under vermiculite in the planted beds and k_V for P in the unplanted beds were significantly higher than those under gravel.

Introduction

The traditional treatment of sewage effluent is very expensive, requires highly trained operators onsite at all times and does not work well on a small scale [1]. Constructed wetlands (CWs) are capable of reducing the treatment cost and the complexity of operation without sacrificing the degree of pollution control [2,3]. CWs are particularly useful for small communities in urban and rural areas with no access to public sewage systems [4]. Subsurface flow constructed wetlands (SSFCW)

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Peer review under responsibility of Cairo University.

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jare.2015.12.002
2090-1232

have demonstrated a consistent capacity to remove organic C and particulate matter from wastewater but have been less successful in the removal of N and P [5].

As SSFCW is a relatively new technology, the operational conditions that affect wetland performance are still poorly defined. The SSFCW can either be planted or unplanted. Several studies have shown that plants enhance treatment efficiency by providing a favorable environment for the development of microbial populations and by oxygenating the system [6–9]. However, Zhu et al. [10] determined that the presence of vegetation causes only minor variations in the efficiency of removing chemical oxygen demand (COD), total suspended solids (TSS), N and P from livestock wastewater. In addition, Coleman et al. [3] showed that gravel alone provides significant wastewater treatment, but vegetation further improves treatment efficiencies.

The high purification efficiency of constructed wetlands can be achieved by choosing suitable growth media. Particle size, surface nature, bulk porosity and pore spaces of the growth media are important factors in this respect [11]. Growth media provide not only physical support for plant growth but also additional sites for biofilm growth and the adsorption of nutrients and promote the sedimentation and filtration of pollutants [12,13]. Gravel is the most commonly used media in CW [1]. The results of Priya et al. [13] showed that sand provides a more efficient treatment than gravel. Sirianuntapiboon et al. [14] determined that the CW with media containing a soil and sand mixture yields the highest removal efficiencies of the pollutants. Several authors [15,16] use different types of media (e.g. vermiculite, zeolite, and lime) to remove certain compound from the wastewater. Constructed wetlands can be operated under continuous or batch feeding modes. The type of feeding mode affects the aeration conditions in the growth media. For example, batch feeding enables the diffusion of oxygen from the air into the bed [17,18]. The inconsistent treatment results concerning the presence of plants, type of media and mode of feeding of CW suggest that further research is needed to optimize the system performance.

Wetland performance is often evaluated on the basis of removal efficiency and the rate of pollutant removal. A first order equation that predicts an exponential decay between the inlet and outlet concentrations under constant influent conditions is used in constructed wetland design. The areal and volumetric rate constants of the model have been used by several authors [19,20,4] to simulate the behavior of the CW hydraulics and describe the removal performance for various pollutants. Few studies [21,22] analyzed the changes in the values of the removal rate constants due to changes in the operational conditions of the wetlands.

The objective of this study was to test the influence of vegetation condition, type of growth media and type of feeding mode on the performance of the VSSFCW, and to calculate the removal rate constants for each pollutant under these conditions.

Material and methods

Source of sewage

The raw sewage effluent in this study was supplied from the Zenien wastewater treatment plant in Giza, Egypt.

Construction of the VSSFCW

VSSFCW units were designed and located in Zenien wastewater treatment plant. The wetland units were constructed from plastic with the dimensions of $0.3 \times 0.3 \times 0.3$ m for length, width and depth, respectively, for an effective volume of 0.0225 m^3. The depth of the growth media was 0.25 m and the sewage level was 5 cm below the surface of the media. The raw sewage effluent was distributed vertically from the top of the unit and the treated sewage was collected from the bottom of the unit. The hydraulic retention time was 0.5 day and the hydraulic loading rate was 0.15 m d^{-1}. The performance of the wetland was tested, in an eight month experiment, under the presence and absence of plants, two types of growth media (gravel and vermiculite), and two modes of sewage effluent feeding (continuous and batch mode). The diameter of the gravel was 5–10 mm, and the porosity of the media was 30%. The vermiculite was obtained from an Egyptian company for vermiculite, its diameter was 5 mm and porosity of the media was 35%.

Initiation of the wetlands

Common reed plants (*Phragmites australis*) were used in this experiment. Healthy plants with a similar state of growth were collected from the Nile bank at Gezerit El Warak, Cairo, Egypt. The plants were cultivated in wetland units with rhizomes at a rate 6 plants/unit. After cultivation, the wetland units were fed with a diluted wastewater (50% tap water: 50% primary treated sewage effluent) for one month. Subsequently, the units were fed with only raw sewage effluent for one month. This sequence of operations was considered as a period for plant growth and establishment.

Calculations

The effect of different operational conditions on wetland performance was evaluated on the basis of percent removal, mass removal rate, areal removal rate constant and volumetric removal rate constant.

The percent removal (removal efficiency) was calculated as follows:

$$\text{Removal efficiency } (\%) = (C_{in} - C_{out})/C_{in} \times 100$$

where C_{in} and C_{out} = inflow and outflow concentrations, respectively (mg L^{-1}).

The mass removal rate (r, in g $m^{-2}d^{-1}$) was calculated as follows:

$$r = q\ (C_{in} - C_{out})$$

r = mass removal rate (g m^{-2} d^{-1}).
q = hydraulic loading rate (m d^{-1}).

Removal rate constants: A first-order degradation approach has been used to predict the removal performance of COD, BOD, TSS, N and P in the constructed wetlands. The rate constants for this model can be defined on either an areal (k_A) or a volumetric (k_V) basis.

The areal removal rate constant (k_A) was calculated using the equation proposed by [25]:

Please cite this article in press as: Abdelhakeem SG et al., Performance of a vertical subsurface flow constructed wetland under different operational conditions, J Adv Res (2016), http://dx.doi.org/10.1016/j.jare.2015.12.002