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Development of the “French system” vertical flow constructed wetland to treat raw domestic wastewater in India

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ABSTRACT

The main aim of our study was to construct a two-stage vertical flow constructed wetland (VFCW) system to treat single household raw sewage water in India under tropical climate. For selecting the plant species different sets of lab experiments were carried out. Two different plant species (*Typha angustata* and *Canna indica*) were considered for their nutrient removal efficiency and biochemical methane potential (BMP) efficiency. Drum experiments were conducted to select the most suitable species for the constructed wetland. Batch assays were conducted in 100 ml bottles in order to determine BMP of plant biomass. The overall nutrient removal efficiency was the same in case of both the plant species that were tested. *Typha angustata* had been selected for planting in the single household wetland system as it is found in the natural wetlands of Goa and they have higher BMP than other species. The nutrient removal of pilot scale VFCW was monitored at two hydraulic loadings at 0.150 m/day and at 0.225 m/day. The removal of Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Kjeldahl Nitrogen (TKN), Ammoniacal Nitrogen (NH_3-N), Total Phosphorous (TP), Total Dissolved Solid (TDS) and Total Volatile Solids (TVS) at 1st stage was 64%, 65%, 15%, 21%, 34% and 54% and for the 2nd stage reactor it is 90%, 88%, 50%,52%, 58% and 71% respectively on an average. After changing HLR (hydraulic loading rate) to 0.225 m/day the removal of COD, BOD, TDS, TVS, TKN and NH_3-N at 1st stage was 61%, 62%, 33%, 40%, 35% and 58% and for the 2nd stage reactor it is 90%, 84%, 61%, 64%, 47% and 82% respectively on an average. As the loading rate increases there is no change in the treatment efficiency of TKN and NH_3-N treatment efficiency increases. However marginal decrease in the treatment efficiency of COD and BOD of the system was observed. The overall footprint of the system got reduced from 1.5 m^2 per person to 0.79 m^2 per person under Goan climatic conditions.

1. Introduction

In India, as per Central Pollution Control Board estimates, the total wastewater generation from Class I cities (no. of cities 498, population greater than 1.0×10^5) and Class II (no. of cities 410, population between 5.0×10^4 and 9.9999×10^4) towns in the country is around 35,558 and 2696 MLD (million liters per day) respectively. However, the installed sewage treatment capacity is just 11,553 and 233 MLD respectively, thereby leading to a gap of 26,468 MLD in sewage treatment capacity (Kaur et al., 2012).

In rural areas of India, the aspect of wastewater treatment plants is mostly neglected because of the lack of infrastructure to improper design, poor maintenance, cost of running is high and lack of technical manpower, the facilities constructed to treat wastewater do not function properly and remain closed most of the time (Konnerup et al., 2009). In this context constructed wetlands (CW) represents a good alternative as it has public acceptance, for being a natural process, low maintenance cost, avoids chemical treatment etc., over conventional wastewater treatment technologies and it is a great alternative for decentralised system in rural India as most of the towns do not have lined sewage system (Álvarez et al., 2017; Ramprasad et al., 2017; Tilak et al., 2017).

There are different types of constructed wetland depending on the flow pattern of the system. French vertical flow constructed wetland system (VFCW) have many advantage over other types of system. The special feature of French VFCW is that it can accept raw sewage in the first stage and so it saves the effort required for the management of primary sludge and as it is a sub-surface vertical flow system it requires very less area than other types of system which makes it very attractive alternative for small towns (Paing et al., 2015; Molle et al., 2005). The main objective of current work was to establish a decentralised VFCW treatment system in tropical climate of India. One of the major

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advantage of adopting French VFCW system is that France has a temperate climate which is very different from the tropical climate of Goa, India which is expected to enhance the microbial growth which will help in better treatment of wastewater (Kantawanichkul et al., 2009).

This study did also focus on the reduction in the size of constructed wetlands and look at the wastewater treatment effectiveness of different plant species (*Typha angustata* and *Canna indica*) and their biochemical methane potential (BMP). The goal was to choose the plant species for the pilot scale studies so as to select the most suitable species for the climatic condition of India. After selection of the plant species, the working of the pilot scale plant will be compared for two different hydraulic loading rates (0.150 m/day and 0.225 m/day).

2. Materials and methods

2.1. Drum experiment

A Drum experiment was first conducted to select the most suitable plant species adapted to the tropical climate of Goa. *Typha angustata* and *Canna indica* were selected as they are easily available and can be found in the natural wetlands of Goa. Four drums, each 200 L total volume and 90 cm in height were tested at the sewage treatment plant of BITS Pilani Goa campus, India. Each unit was filled with gravel layers similar to a 1st stage VF system (Table 1). A ventilation system was provided by perforated pipes at the bottom of the drum connected to the surface (Fig. 1A). The first drum was left unplanted (control) and other two were planted with monoculture of *Typha angustata* and *Canna indica*. Drums were first fed during first month with treated water to establish the plants. Then drums were fed with raw sewage during next two months with a hydraulic loading of 0.11 m/day corresponding to an organic loading of 148 g COD $m^{-2} d^{-1}$.

2.2. Biomethanation potential (BMP) of the plant biomass generated in the wetland

Simultaneously with drum experiments, the BMP assay was conducted for the plant biomass that was used in wetlands. Cellulose, hemicelluloses and lignin content of the samples were analyzed for each plant biomass by VAN SOEST method (Fig. 3). The BMP assay for the plants were studied in 100 ml serum bottles at room temperature at five different substrate concentrations – 0.5, 1, 2, 3, 4 gVS/l, to determine the highest substrate concentration. The slurry from already existing biogas plant in the campus was used as inoculum, which was enriched in ethanol before carrying out the anaerobic digestion studies. BMP assay was carried out according to the methods presented by Owens and Chynoweth (1993), Angelidaki and Sanders (2004), Angelidaki et al. (2009), Prabhudessai et al. (2013) and Yadav et al. (2016). The volume of biogas produced every day was measured by water displacement method up to 29 days. The purity and percentage composition of gases was measured by gas chromatography (Chemito Technologies gas chromatograph) on 5th, 12th, and 18th day of the experiment.

2.3. Pilot scale VFCW

Two stage VFCW was constructed inside the campus of BITS Pilani KK Birla Goa campus. The VFCW was made up of cement and cement bricks and it was also plastered to make it leak proof. The surface area of stage 1 VFCW was of 4 m^2 and the surface area of stage 2 was of 1.88 m^2. The construction design of the wetland is shown in Fig. 4. The ventilation system was similar to the one of the drum experiment (Fig. 1B). Both the stages of wetlands were filled with different sizes of gravels and sand from river as given in Table1. The gravels and sand from river have high hydraulic conductivity which helps to provide better surface for the developments of biofilms and nutrition adoptions (Sundaravadivel and Vigneswaran, 2003). The system was planted during the first week of April 2015 and fed with treated wastewater from the campus treatment plant to favor plant development during 1 month. The system was then fed with raw wastewater coming from the primary tank of the campus sewage treatment plant. The stage 1 consist of three filters beds to provide one-day loading period and two days of resting periods, which were operated in parallel; each filter bed was fed with 0.05 m/day of raw sewage in three batches a day i.e. total 0.15 m/day for one day and rested for next two days. The treated water from stage 1 was collected in an underground tank and from there it is fed to stage 2 through a motor pump. The stage 2 consist of two filter beds; each filter bed was fed alternatively each day with the same hydraulic loading rate but in case of second stage the resting period was only for one day. The 0.150 m/day hydraulic loading rate was maintained for 28 weeks. For the next set of experiments, the system was fed at higher hydraulic loading of 0.225 m/day to check efficiency for nutrient removal and to decrease the footprint required per person. The second set of experiment was continued for 12 weeks before the rainy season started.

Table 1
Design characteristic of VFCW (Paing et al., 2015).

Filter media	Stage 1	Stage 2
River gravels	40–50 cm gravel 2/8 mm 15–20 cm gravel 10/20 mm 20 cm gravel 20/10 mm	40 cm sand 0/4 mm 15–20 cm gravel 4/10 mm 20 cm gravel 10/20 or 20/40 mm

2.4. Analytical methodology

The samples for analysis were collected after each batch event and mixed at the end for the analysis. The samples were analyzed for Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Kjeldahl Nitrogen (TKN), Ammoniacal Nitrogen (NH_3-N), Total Phosphorous (TP), Total Dissolved Solid (TDS) and Total Volatile Solids (TVS). BOD was determined by WTW OxiTop® and the remaining parameters were determined by using Standard Methods (APHA and WEF, 2005).

3. Results and discussion

3.1. Drum experiment

The COD measured at the outlet of Control, *Typha angustata* and *Canna indica* planted beds are presented in Table 2. The planted drum performances in terms of COD removal were found to be very similar to unplanted drum, this may be because the system is very new and was run for a very short period of 8 weeks.

The Total Kjeldahl Nitrogen (TKN) removal efficiency of Control, *Typha angustata*, and *Canna indica* planted drums was observed to be 67 ± 3.5 mg/L, 60 ± 5 mg/L, and 77 ± 8 mg/L respectively (Table 2). *Canna indica* grows very fast and covers the wetland surface completely providing high plant biomass to wetland volume ratio which increases the contact between plant roots and wastewater and provides high plant sink for nutrient removal (Zhang et al., 2007). On an average 35% and 34% removal efficiency of Ammoniacal Nitrogen (NH_3-N) and TKN respectively was observed in both the plant species used. There is no difference in the removal efficiency. This may be because of the wetlands were not old enough and the plant roots were not grown enough to show proper bacterial activity for the nitrification and denitrification of the nitrogen (Calheiros et al., 2009) and for the mineralization of organic matter, supply of oxygen and alternative electron acceptors is very important factor (Paredes et al., 2007).

With reference to the phosphorous removal (Table 2) it can be observed that there is no considerable difference in the removal efficiency of the different plant species used and the control drum. This show that

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