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Treatment efficiency of vertical flow constructed wetland systems operated under different recirculation rates

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1. Introduction

Dairy farm washings contains urine, manure, as well as detergents, spilled milk, mucus, and have adverse effect on the surrounding environment (Kato et al., 2013). The concentration of contaminants such as organic and inorganic matter in dairy wastewater are significantly high and tends to increase throughout the year (Healy et al., 2007). Disposal of dairy effluent has become a major economic and social problem as its release into land, rivers or other aquatic bodies offers serious problems to health and hygiene (Ghermandi et al., 2010; Ye et al., 2012) therefore this wastewater is necessary to be treated before its disposal. However, the available treatment techniques are least affordable due to high operation and maintainence cost. In the recent years, Constructed wetlands (CWs) have gained popularity in treating dairy farm wastewater because of relatively low operation, installation costs and maintainence requirements (Pachpute et al., 2014).

Constructed wetlands (CWs) are those artificial systems that have been designed and constructed to utilize natural substances including wetland vegetation, soils and microbial assemblages for treating dairy wastewater (Hammer and Bastian, 1989). In a Constructed Wetland system, chemical, physical and biological processes occur in combination and are responsible for pollutant removal from wastewater. Treatment in CW includes processes such as sedimentation, filtration, sorption, precipitation, plant uptake and microbial degradation (Kadlec et al., 2000). The treatment occurs when wastewater flows through the wetland filter media and plants. Within the wetland filter medium, wastewater interacts with plant roots. This interaction leads to rhizofiltration and sedimentation. Interaction between microbes and pollutants results in biological degradation of organic pollutants. (Mthembu et al., 2013). Root hairs of the plants provide aerobic conditions that support microbial activities. Degradation of organic and inorganic matter occurs due to presence of aerobic and anaerobic microorganisms. In general, there are two designs of CWs: Surface and Sub-surface flow systems. The sub-surface flow system further includes two designs i.e. Horizontal Sub-surface flow system and Vertical Sub-surface flow system (Imfeld et al., 2009). Both Horizontal and Vertical flow systems differ in their mode of flow of wastewater.

In this research work, vertical flow CW system working under different recirculation rates has been used for treating dairy farm wastewater. In a vertical flow CW system, wastewater is dosed vertically allowing it to percolate slowly through the filter media to the bottom of the system. During its percolation, treatment occurs by various physical, chemical and biological processes. As compared to Horizontal flow CW, this system provides good pollutant removal efficiency specifically for Nitrogen. Vertical flow system supports ammonium oxidation process (Felde and Kunst, 1996). The roots, shoots, litter from plants, along with filter materials used, supports growth of microbial biofilm and other associated microorganisms which serves as essential components of the system (Hiley, 1995). Among the different design upgradations of vertical flow CW systems, partial recirculation of treated water to the inlet has been adopted by most of the researchers as it improves the nitrogen elimination efficiency and increases the removal of organics and suspended solids in a classical VSSF CW system (Garcia-Perez et al., 2011, Prost-Boucle and Molle, 2012) and helps in achieving higher purification rates especially for Nitrogen and Phosphorus. Along with this, recirculation arrangement helps in diluting the high strength influent wastewater before it enters the wetland cells and provides organic substrate for denitrification. Previous studies, i.e., Brix and Johansen (2004), Brix and Arias (2005) reported that on applying recirculation in treatment procedures, transferring of a portion of nitrified VSSF effluent to the primary inlet tank promotes denitrification process as a result of organic matter (BOD and COD) biodegradation. According to a recent study (Ilyas and Masih, 2018) partial effluent recirculation back to the inlet primary tanks increases the activities of aerobic microbes and provides better removal of organic matter from wastewater.

Oxygen transfer is a vital process in many wastewater treatment processes, where oxygen is transferred from gaseous to liquid phase. Oxygen is required in the system for biological degradation by microbes and aeration of the wastewater. The demand is mainly associated with oxidation of organic and carbonaceous matters (Barge et al., 2014). In vertical flow CW, removal of pollutants depends on aeration capacity or commonly called as ‘Oxygen Transfer Rate’ (OTR). This can also be performed by planted macrophytes having their roots growing in the

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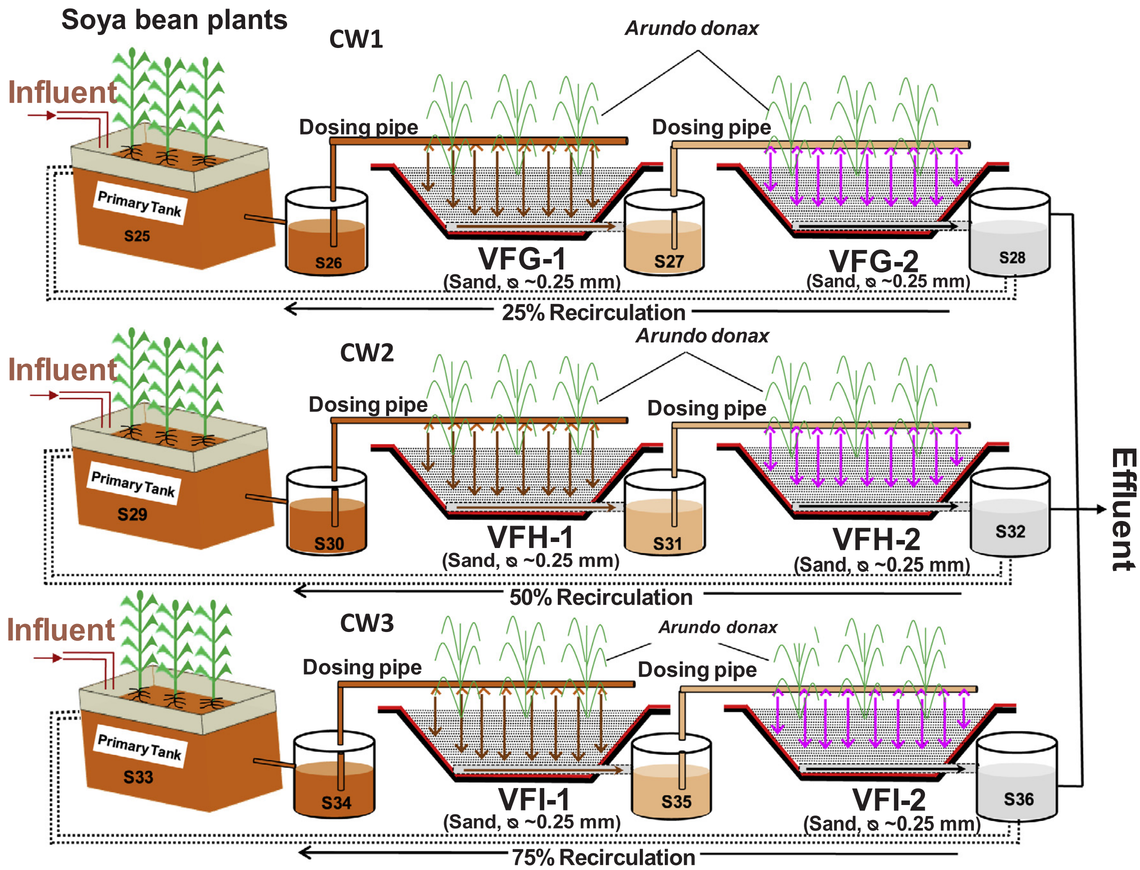

Fig. 1. Schematic design of Vertical sub-surface Flow Constructed Wetland systems.

filters (Noorvee et al., 2005). This research work was carried out to assess the effect of recirculation on pollutant removal efficiency of Vertical sub-surface flow CW systems and also to investigate the optimum recirculation rate required for maximum removal of pollutants from wastewater.

2. Materials & methods

2.1. Description of study site

The present research work has been carried out using three different Verical Sub-surface Flow CW systems (CW1 to CW3) each with an area of 4 m^2 constructed near the dairy farm attached to Graphic Era (Deemed to be University), Dehradun, India (Figs. 1 & 2). Each CW system consists of two vertical flow beds (first bed: 2.5 m^2 & second bed: 1.5 m^2). The depth of each VF bed is of 0.7 m. All the CW systems were filled with sand as filter material and were planted with giant reed, *Arundo donax*. The perforated PVC drainage pipes were placed at the bottom of each CW beds before filling filter material and dosing pipes were placed on the top surface of bed. The major advantage of using sand as filter media comprises of very fine particle size (d_{10} ~ 0.25 mm) which helps in settling of solid particles over the bed surface. Moreover, Sand particles have good cation binding capacity which results in precipitation of phosphorous present in wastewater.

A volume of 220 L of dairy wastewater (HLR: 55.0 mm m^{-2}), was dosed vertically (in batch dosing process) in each of the 3 wetland units and allowed to retain inside the first bed for an HRT of 24 h. The drainage pipes for the first bed were closed with a stopper to maintain HRT. After 24 h, water was drained out from the outlet tanks of first units and further dosed to second bed with HRT of 20 min. Samples were collected from the final outlets of each CW unit. Initially, the system was operated without recirculation for 3 weeks and samples were collected once a week. The CW units were operated for 7 months each with and without recirculation arrangement.

For carrying out recirculation process, water from final outlet tanks was recirculated back (in batch dosing process) into their respective recirculation tanks, placed before the first bed of each unit. These recirculation tanks contained floating bed prepared using PVC pipes and bamboo sticks and planted with Soybean plants. Recirculation arrangement was fixed as: 25%, 50% and 75% in CW1, CW2 and CW3 respectively (Fig. 1). Further, dosing was done in similar pattern in all CW units and sampling was done from the outlet points of CW1, CW2 and CW3. Sampling was done twice a month and samples were collected in 1 L plastic bottles (Fig. 2) for further analysis.

2.2. Analytical procedures

Physical parameters such as pH, temperature, ORP, EC, TDS, Salinity were recorded at site during sampling using Multiparameter system (Hach SensION + MM150) and DO was measured using DO Meter and sensor (Hach SensION). The samples were brought to the laboratory and stored at 4 °C in refrigerator and were analyzed by using standard methods of examination of water and wastewater (APHA, 2005) and 'Hach Manual'. The samples were analyzed for TSS using colorimetric method, BOD_3 using 3-days incubation method, total Nitrogen using Persulfate Digestion method, NH_4-N using Salicylate method, NO_3-N using Cadmium Reduction method, and total P using Molybdovanadate method. Comparative analysis was done to investigate the appropriate recirculation rate (25%, 50% and 75%) for maximum removal of pollutants from wastewater.

The efficiency of each CW unit for each parameters was calculated using the following equations (Sharma et al., 2013):

$$Purification\ rate\ (\%) = (C_i - C_o) * 100/C_i \quad (1)$$