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Effects of load fluctuations on treatment potential of a hybrid sub-surface flow constructed wetland treating milking parlor waste water

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ABSTRACT

A hybrid sub-surface constructed wetland (CW) system consisting of 2 gravel filled vertical sub-surface (VFa & VFb) beds, each 160 m^2 in size planted with *Phragmites australis* and a sand filled horizontal sub-surface (HF) bed, 336 m^2 in size, planted with rice was operated from 2007 to 2010 for treating milking parlor waste water in Hokkaido, Japan. Hybrid CW system received huge fluctuations in average yearly inlet loads for TSS (526.0–1259 $mg\,L^{-1}$ & 2.7–9.0 $g\,m^{-2}\,d^{-1}$), BOD_5 (1,080–2,114 $mg\,L^{-1}$ & 8.4–14.4 $g\,m^{-2}\,d^{-1}$), COD(1,962–7,085 $mg\,L^{-1}$ & 14.5–50.0 $g\,m^{-2}\,d^{-1}$), TN (116.0–243.0 $mg\,L^{-1}$ & 0.8–1.6 $g\,m^{-2}\,d^{-1}$), NH_4-N (54.0–90.0 $mg\,L^{-1}$ & 0.40–0.64 $g\,m^{-2}\,d^{-1}$), TC (1,022–2,215 $mg\,L^{-1}$ & 6.0–15.1 $g\,m^{-2}\,d^{-1}$), TP (15.3–41.7 $mg\,L^{-1}$ & 0.11–0.28 $g\,m^{-2}\,d^{-1}$) during study period. Average yearly purification and removal rates were least fluctuated for TSS (95.7–99.4%); moderately for BOD_5 (86.1–95.7%), COD(87.5–96.1%) and TC (79.5–91.3%); highly for TN (72.6–90.6%), NH_4-N (62.9–85.3%) and TP (64.8–87.2%). A sharp decrease in TP purification and removal rates were observed in 2008 due to sharp decrease in influent TP concentration in 2008 compared to 2007. OTR values for VF(a), VF(b), HF bed and total system were observed as 21.7, 19.3, 4.8 and 12.3 $g\,O_2\,m^{-2}\,d^{-1}$ respectively. Average k value of hybrid CW system for BOD_5, TN, NH_4-N and TP during study period were 7.0 ± 1.8, 7.4 ± 3.3, 5.6 ± 4.1 and 4.9 ± 2.0 $m\,yr^{-1}$ respectively.

Average concentration of TSS, TP, TN and NH_4-N in the final effluent for all years were below the discharge limit value of: 150 $mg\,L^{-1}$ for TSS; 8 $mg\,L^{-1}$ for TP, 60 $mg\,L^{-1}$ for TN and NH_4-N. However, average BOD_5 and COD concentrations could not meet the discharge limit value of 120 $mg\,L^{-1}$ during 2007 and 2008.

1. Introduction

Milking parlors discharge nutrient-rich wastewater which has high potential of polluting surface and/or ground water. Most of times, this wastewater is either stored and irrigated onto land (Moir et al., 2005) or treated by conventional methods such as trickling filters, activated sludge process, anaerobic lagoon and aerated lagoons (Munavalli and Saler, 2009), however all these treatment methods are expensive. Thus, small-scale milking parlor owners often show no/less interest in adopting any of these technologies. On the other hand, constructed wetlands (CWs) which are simple in design and operation as well as cost effective has been tested worldwide to treat different types of wastewater such as domestic, industrial, acid mine drainage, agricultural runoff and land fill leachate (Beutel et al., 2009; Nyquist and Greger, 2009; Kadlec and Zmarthie, 2010; Serrano et al., 2011; Vymazal, 2011).

Among the recent developments, hybrid sub-surface CWs are becoming more popular because of their higher treatment potential (Noorvee et al., 2005; Öövel, 2007; Tszynska and Obarska-Pempkowiak, 2008; Justin et al., 2009; Singh et al., 2009; Kato et al.,

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2005, 2010, 2013; Sharma et al., 2012; Serrano et al., 2011; Vymazal and Kröpfelová, 2011). The Performance of a CW is affected by a range of factors such as operational mode (loading rate, continuous or batch-load) and environmental conditions (climate, season, temperature etc.) (Chazarenc et al., 2007).

Hokkaido is the largest milk producing region in Japan and has 7,809 dairy farms and 1374 milking parlors. Most of these dairy farms in Hokkaido are small-scaled farms and discharge large volumes of wastewater everyday. This paper presents the effects of load fluctuations on the treatment efficiencies, OTR and k value of a real-scale hybrid sub-surface flow CW system constructed in Embetsu, Hokkaido in November, 2006 and operated for 3 years under high load fluctuations during milking parlor wastewater treatment.

2. Materials and methods

2.1. Site description

The hybrid sub-surface CWs consisting of three beds in series (VFa, VFb and HF) is located at a privately owned dairy farm in Embetsu, Hokkaido (44° 45′ N, 141° 48′ E). VF beds were constructed in November 2006 according to design recommendations of Cooper (1997; Cooper, 2005). The bed sizes were determined using following equations:

$$OTR = Q * \{(BOD_{In} - BOD_{Out}) + 4.3 * (NH_4 - N_{In} - NH_4 - N_{Out})\} * 100/\text{Total area} \quad (2.1)$$

OTR (Oxygen transfer rate): $g\,O_2\,m^{-2}\,day^{-1}$

Q(Flow rate): Influent Volume($m^3\,day^{-1}$); Total area:m^2; BOD and NH_4–N: $mg\,L^{-1}$

OTR of beds were considered as follows (Cooper et al., 1997; Cooper, 2005):

VF beds= $28\,g\,O_2\,m^{-2}\,day^{-1}$, HF bed = $15\,g\,O_2\,m^{-2}\,day^{-1}$

Limit loading rate (LLR) was calculated using following equation (Cooper et al., 1997; Cooper, 2005):

$$LLR = \text{Flow rate}(Q) * BOD_{In} * 100/\text{Total area} \quad (2.2)$$

LLR = 25(g $BOD_5\,m^{-2}\,day^{-1}$) or 50 (g $COD_{Cr}\,m^{-2}\,day^{-1}$)

Area of HF bed was kept nearly equal to areas of both VF beds together so that both beds (VF &HF) could equally contribute in treatment of wastewater.

2.2. Filter material, bed depth, surface vegetation

The first, VF(a) and second, VF(b) beds are vertical sub-surface flow beds, each 160 m ^{2} in area with a depth of 0.71 m. Both beds were gravel filled and planted with common reed (*Phragmites australis*). (Fig. 1 & Table 1). At the bottoms of both VF beds interconnected perforated pipes were placed to collect and drain the treated waste water from the beds. In VF(b) bed, recycling of effluent (450%) from outlet tank (S3 location) to inlet tank (S2 location) was carried out during growing seasons of 2008, 2009 and 2010.

Third bed is HF bed, 336 m^2 in area with a depth of 0.7 m. HF bed was filled with washed sand from top to bottom. The bottoms of all three beds were built with a 1% slope, lined with high density polyethylene liner and circumferences of the beds were kept high to avoid seepage of waste water to underground water. In HF bed four different local varieties of forage rice were planted for assessing the nutrient recycling using nutrient uptake process of rice. Rice was planted in May month and harvested in October month in year 2007 and 2008. In August, 2009, supersole® was added on the HF bed surface (0.05 m thickness) and planted with 300 reed plants.

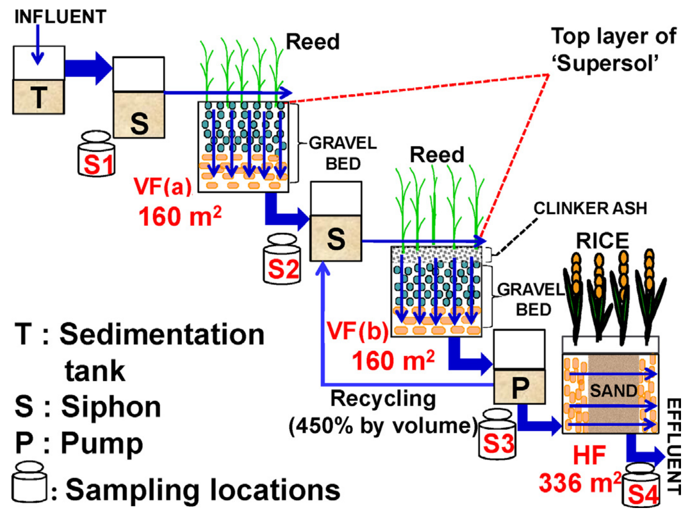

Fig. 1. Schematic layout of Hybrid Sub-surface flow CW system at Embetsu, Hokkaido.

Supersol® is a porous material manufactured from recycled glass bottles (TRIM Co. Ltd., 2012). It has a low density of 0.4 g cm^{-3} due to which it floats on the bed surface during influent dosing and acts as an obstruction to the suspended solids (SS) of influent. This lead to uniform distribution of SS on the bed surfaces, which helps in preventing clogging of beds. Supersol® has an additional benefit of acting as an insulating material during cold winter and helps in preventing freezing conditions at the bed surfaces (Kato et al., 2013)

Dosing wastewater at VF beds was carried out using Siphon. In HF bed, an electric pump was used for dosing wastewater instead of siphon because of hydraulic limitations. Waste water was pretreated in a sedimentation tank (5.4 m^3) for settling suspended solids.

2.3. Sampling measurement and analysis

Sampling was carried out from November 2006 to October 2010 at sampling locations S1, S2, S3, S4 (Fig. 1). S1 is the inlet point and S4 is the final outlet point. Samples were collected once in a month, preserved and analyzed for TSS, COD_{Cr}, BOD_5, total N (TN), NH_4-N, NO_3-N, total P (TP), PO_4-P, organic-P, total coliform and total carbon (TC). DO, pH, ORP and EC were measured at field during sampling. TSS was measured by suction filtration method (filtration at 45 μm and drying at 105 °C) (APHA, 1992). TN, and TC were measured using an elemental analyzer (Elementar vario MAX; Elementar Analysensysteme GmbH, Hanau Germany) (Kato et al., 2013). NH_4-N, TP and PO_4-P were measured by Spectrophotometric method ((APHA, 1992). NO_3-N was measured by Ion Cromatograph(Shimadzu) (APHA, 1992). Total coliform was measured using Petrifilm plate count method (APHA, 1992). BOD_5 was measured by 'JIS K 0121' method of Japanese Industrial standards (Kato et al., 2013). COD_{Cr} was measured using 'HACH DR2800 portable spectrophotometer (Kato et al., 2013).

2.4. Calculations of k values, OTR, OTR′ and statistical analysis of data

The removal of BOD_5, TP, TN and NH_4-N in hybrid sub-surface CWs in Embetsu was also described using an area-based