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Effluent quality and reuse potential of domestic wastewater treated in a pilot-scale hybrid constructed wetland system

Selma Ç. Ayaz [a], Özgür Aktaş [a, b, *], Lütfi Akça [c, d], Nur Fındık [a]

[a] TUBITAK MRC, Environment and Clean Production Institute, Gebze, Kocaeli, Turkey
[b] Istanbul Medeniyet University, Department of Bioengineering, Unalan, Uskudar, Istanbul, Turkey
[c] Istanbul Technical University, Environmental Engineering Dept., Maslak, Istanbul, Turkey
[d] Ministry of Forestry and Hydraulic Works, Undersecretariat, Ankara, Turkey

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ABSTRACT

The study investigates treatment and reuse potential of domestic wastewater of a small community of about 30 people sequentially by anaerobic pretreatment followed by horizontal (HSSF-CW) and vertical (VSSF-CW) sub-surface flow constructed wetlands operated in series. The organic and suspended solids load to the hybrid wetland system was decreased by anaerobic pretreatment. HSSF-CW mainly removed organic matter and supported denitrification whereas VSSF-CW mainly obtained nitrification and phosphorus removal. Recirculation of the effluent increased particularly total nitrogen removal in the wetland system. The study involves evaluation of the whole system in terms of effluent quality. It was achieved on average >95% organic matter and >90% nitrogen removal in the hybrid constructed wetland system with anaerobic pretreatment at a specific wetland surface area of only about 1 m^2 per person. Average mass removal rates were 21.17 gCOD/m^2day, 5.58 $gBOD_5/m^2$day, 2.78 gTKN/m^2day, 1.35 gTN/m^2day, 0.44 gTP/m^2day and 5.21 gTSS/m^2day throughout the total duration of the operation. Consequently, the effluent met the regulations for discharge limits for organic matter and suspended solids. COD and TN concentrations decreased to below 20 mg/L in the effluent. It was also shown that effluent of the system could be reused for irrigation if it is disinfected properly.

1. Introduction

Constructed wetlands are widely used for the treatment of domestic wastewaters and preferred over natural wetlands since they are easier to control. Constructed wetlands have several advantages including low investment and operation costs as well as low or no sludge production compared to classical activated sludge systems. Besides, sub-surface flow systems offer a pathogenically safe environment. Subsurface-flow constructed wetlands are designed in two different types, horizontal (HSSF-CW) and vertical (VSSF-CW). These two types can be sequentially used as hybrid constructed wetland systems. Literature studies showed that domestic wastewaters could be successfully treated with efficient organic matter and nitrogen removal by hybrid constructed wetlands in Mediterranean countries. It was possible to achieve concentrations of <15 mg/L BOD_5, <0.5 mg/L NH_4^+-N and <1 mg/L NO_3^--N in the effluent (Masi et al., 2010) and high efficiencies amounting to 99.4% BOD, 97.0% COD, 99.5% suspended solids (SS) and 99.0% ammonia nitrogen removal (Kayranli et al., 2010). Hybrid constructed wetlands are advantageous such that horizontal-flow constructed wetlands mainly provide organic matter removal and denitrification, whereas vertical-flow wetlands provide nitrification (Ayaz et al., 2011).

Anaerobic pretreatment before constructed wetland systems is very advantageous. Removal of suspended matter in anaerobic reactors protects constructed wetlands from clogging (Ayaz et al., 2011), and this consequently results in higher service life of wetlands. Also, removal of organic matter in anaerobic reactors decreases the specific area required for the consecutive wetland beds. This is very important considering that requirement of a large area is the main disadvantage of constructed wetlands. In a literature study, it was reported that in CW systems combined with anaerobic pretreatment, the TSS loading rate was reported to be 30–50% less than that applied in CWs combined with classical pretreatment technologies such as septic and Imhoff tanks. This prevented or

* Corresponding author. Istanbul Medeniyet University, Department of Bioengineering, Unalan, Uskudar, Istanbul, Turkey.
E-mail address: aktasozg@gmail.com (Ö. Aktaş).

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delayed gravel bed clogging in CWs and 30–60% reduction was provided in the required wetland area owing to increased organic matter removal in anaerobic reactors (Alvarez et al., 2008). For the treatment of domestic wastewaters, psychrophilic (10–20 °C) and sub-mesophilic anaerobic treatment is getting more widely applied. Many studies showed that temperature is not a limiting factor in anaerobic treatment applications if an appropriate process design is chosen (Ayaz et al., 2012a). Thereby, external heating of anaerobic reactors can be eliminated.

In the present study, a hybrid constructed wetland system was combined with anaerobic reactors operating at ambient temperatures for the treatment of domestic wastewater at pilot-scale. The treatment performances and effluent concentrations were monitored at each treatment step. It was aimed at evaluation of the whole system in terms of effluent quality and the potential for water reuse.

2. Materials and methods

The treatment system received 2000–3000 L/day of domestic wastewater corresponding to about 30 inhabitants. The characteristics of the influent domestic wastewater fluctuated within concentrations of chemical oxygen demand (COD): 566 ± 140 mg/L, 5-day biochemical oxygen demand (BOD_5): 158 ± 49 mg/L total suspended solids (TSS): 217 ± 88 mg/L, total Kjeldahl nitrogen (TKN): 67 ± 15 mg/L, NH_4–N: 51 ± 12 mg/L, PO_4–P: 8.5 ± 4.8 mg/L, pH: 7.84 ± 0.24, alkalinity: 367 ± 46 mg $CaCO_3$/L, Temp: 20.6 ± 4.0 °C, dissolved oxygen (DO): 0.53 ± 0.32 mg/L (mean ± std. dev, n = 110 for all parameters).

2.1. Anaerobic reactors

Pretreatment of domestic wastewaters was performed in an upflow anaerobic sludge bed (UASB) reactor and an anaerobic baffled reactor (ABR) operated in parallel (Fig. 1). Both reactors (UASB and ABR) were operated at ambient temperatures such that temperature of the wastewater was observed in the range of 13–28 °C (psychrophilic and sub-mesophilic) depending on the seasonal variations. However, the reactors were covered with insulation material in order to prevent the adverse effects of sharp temperature changes. Volume of UASB and ABR were 0.5 and 1 m^3, respectively. A flocculent anaerobic sludge was used in both reactors at a volumetric ratio of 15%. Mixed liquor suspended solids (MLSS) concentration of the seed sludge was 9560 mg/L and its mixed liquor volatile suspended solids (MLVSS) concentration was 7300 mg/L resulting in MLVSS/MLSS ratio of 0.76. Both reactors were operated at a hydraulic retention time of about 12 h. Organic loading rates were in the range of about 0.3–0.7 kg COD/m^3day in both reactors. Total flow rate to anaerobic reactors was between 2000 and 3000 L/day.

2.2. Hybrid constructed wetland system

The hybrid wetland system consisted of a serially operated horizontal sub-surface flow constructed wetland (HSSF-CW) and a vertical sub-surface flow constructed wetland (VSSF-CW) (Fig. 1). Domestic wastewater was introduced by gravity into HSSF-CW. HSSF-CW effluent was pumped batch-wise to VSSF-CW. Effluent from VSSF-CW was batch-wise recirculated to the influent of HSSF-CW. HSSF-CW aimed to achieve organic matter removal and denitrification. On the other hand, VSSF-CW aimed to achieve nitrification. Aeration pipes were used in VSSF-CW to enhance oxygen transfer and nitrification. Marble stone, sand, lime stone and gravel were used as filling material in VSSF-CW, whereas HSSF-CW was filled only with gravel. The flow rates to the wetlands were 2–3 m^3/day, base slopes were 0.001 and *Phragmites australis* was used in both wetlands with planting densities of 4 rhizomes/m^2. HSSF-CW beds had a surface area of 18 m^2, hydraulic retention time (HRT) of 34–53 h, hydraulic loading rates (HLR) ranging between 111 and 167 L/m^2. day and bed porosity of 28%. On the other hand, VSSF-CW beds had a surface area of 13.7 m^2, HRT of 12–24 h, HLR ranging between 146 and 219 L/$m^{2\cdot}$ day and bed porosity of 33%. Bed depth was 0.8 m in both types of wetlands. Specific surface area of the whole system was about 1 m^2 per person.

The system was operated at 5 periods each lasting about 4 months. Period I represents the results from operation in summer, and Period II represents results from winter months. In the first three periods, effluent recirculation was not applied (R:0). However, with the start of Period III, VSSF-CW was operated at intermittent fill-and-draw mode in order to increase dissolved oxygen concentrations. In periods IV and V, fill-and-draw mode was continued, but effluent of VSSF-CW was recirculated at a ratio of 100% (R:1/1) and 200% (R:2/1), respectively. The average influent water temperatures ranged between 16 and 23 °C during these 5 periods. Sampling was made weekly from the inlet and outlet of the UASB and ABR, inlet and outlet of the HSSF-CW and outlet of the VSSF-CW as final effluent.

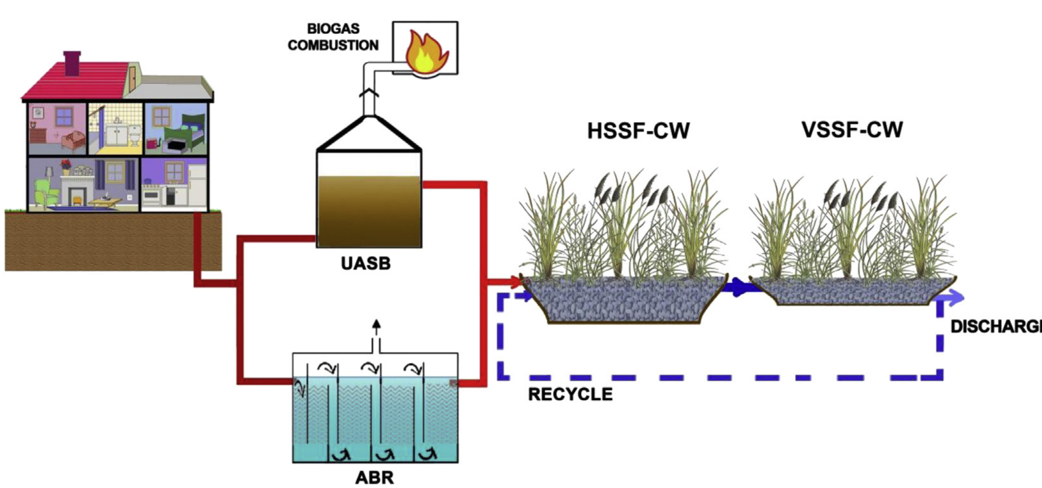

Fig. 1. Schematic diagram of the treatment system.