Influence of microbial fuel cell integration on organic matter and nutrient removal in a vertical constructed wetland for wastewater treatment

Thais G.*, Juan Pablo M., Vidal G.

Environmental Engineering & Biotechnology Group, Environmental Science Faculty & EULA–CHILE Center, Universidad de Concepción, Concepción, Chile.

*corresponding author: Thaís González: e-mail: tgonzalezp@udec.cl

Abstract

The combination of constructed wetlands (CWs) and microbial fuel cells (MFCs) has emerged in recent years with the purpose of enhancing wastewater treatment efficiency of CWs while simultaneously generating electricity. Taking the above into account, the aim of this study is to evaluate the influence of MFC integration on organic matter and nutrient removal in a constructed wetland. The results showed that NH_4^+-N concentration reduced from 66.5 ±9.4 at day 0 (influent) to 4.5±0.4 mg/L and 7.03±3.93mg/L for the integrated system and control system, respectively. In terms of the NH_4^+-N removal efficiency, an enhancement of the nitrification rate (νNi) was observed when MFC was integrated in VSSF (120.6±1.5 mg/m^2 d for control system and 166.8±2.3 mg/m^2 d for integrated system). The average COD removal efficiencies were 85.36±2.67% and 94.2±5.9% in the CW and CW-MFC, respectively, obtaining a voltage close to 250 mV. The maximum power density generated was 4.75 mW/m^2. In conclusion, the removal efficiencies of COD and NH_4^+-N in VSSF were 85.4 and 88.4%, respectively, while in CW-MFC were 94.3 and 93.2 %. Therefore, the integrating of a MFC into CW does not have adverse effects on the capacity of the CW to efficiently domestic wastewater treatment.

Keywords: Microbial fuel cell, Vertical constructed wetland, Chemical oxygen demand, Ammonium, Wastewater treatment.

1. Introduction

Constructed Wetlands (CWs) are engineered systems that have been designed to utilize natural processes in wastewater treatment (Stefanakis and Tsihrintzis 2012). Microbial Fuel Cell (MFC) is a bioelectrochemical device, which direct converts chemical energy to electrical energy through the action of electrochemically active microorganisms (EAMs) (Rabaeay and Vestraete 2005). The combination of CW–MFC is an emerging technology that has gained attention because of its potential use as energy recovery system in the form of electricity during wastewater treatment (Oon et al., 2015). Domestic wastewater contains approximately 10 times more chemical energy than the energy applied on cleaning it, but the focus of conventional wastewater treatment systems has been only to meet the discharge standards by removal the carbonaceous and nutrient compounds. Furthermore, wastewater treatment requires about an energy of 0.5-2 kWh/m3 which depends on the process and wastewater composition. MFC need a redox gradient – an anaerobic anode and aerobic cathode – that can be found naturally in CWs depending on flow direction and wetland depth (Doherty et al., 2015). In this study, we evaluated the of microbial fuel cell integration on organic matter and nutrient removal in a vertical constructed wetland for wastewater treatment.

2. Methods

2.1. Experimental systems construction, configuration and operation

Two experimental units of vertical subsurface flow were built at a laboratory scale using identical columns of acrylic with an internal square section of 0.15 m by 0.15 m and 0.7 m high. Where: a) VSSF stands for a constructed wetland system without Microbial Fuel Cell and b) VSSF-MFC is the microbial fuel cell integrated into the constructed wetland. The configuration for CW system, consisting of a bottom layer of 25cm of gravel, then an intermediate layer of 20 cm of zeolite and a top layer of 25 cm of gravel. For the VSSF-MFC system, from bottom to top were filled with a base of 10 cm of gravel, then 10 cm of activated granular carbon (anode), 20 cm of zeolite, 10 cm of granular activated carbon (cathode) and 10 cm of gravel. The anode and cathode were connected to an external electric resistance of 1000 ohm. The systems were feed with a synthetic solution that simulated physically pretreated domestic wastewater. The composition of domestic wastewater used glucose (0.12 and 0.32 g/L) and acetate (0.12 and 0.32 g/L) as carbon source (Villaseñor et al., 2013). An individual of Schoenoplectus Californicus was planted in both systems. Table 1 shows the operational parameter of the systems.

Table 1. Operational parameters during different stages.

Operational parameters	Unit	Stage		
		Start-up	I	II
COD	mg/L	250	500	1000
HRT	d	7	10	10
Q	L/d	0.7	0.5	0.5
OLR	COD g/m^2 d	7	12	28
Operational time	d	8	50	40

Table 2 shows the organic matter degradation measured as COD. The control system (VSSF) as well as the integrated system (VSSF-MFC) showed effluent with COD removal efficiency between 80-90% and 89-94% from an average influent with COD equals to 501 ±30 mg/L for the stage I and 1036±61 mg/L for the stage II. The activated carbon grains bonded with EAMs are capable to extract electrons from organic matter and storing them inside. These characteristics would improve the adhesion of microorganisms on the anodic surface, which could have improved the removal COD in the CW systems with integrated fuel cells (Sonawane et al., 2016).

Table 2. COD degradation performance of VSSF and VSSF-MFC during the different operation stages.

System	Stage	COD [mg/L]		Removal efficiency
		Initial	Final	
VSSF	I	471 ±7.5	56 ±2.1	80 ±3.7
	II	1106 ±1.9	65 ±0.5	90 ±0.8
VSSF MFC	I	531 ±4.7	55 ±3.5	89 ±8.6
	II	967 ±7.0	102 ±6.6	94 ±7.0

Figure 1 shows the average removal efficiencies of NH_4^+-N. For VSSF the obtained values were 89±1.8 % and 91±2.1 % in stage I and II, respectively. In VSSF-MFC varied from 93±0.26% to 96±0.74%. In general, the observed tendency for VSSF and VSSF-MFC systems was a decrease in the NH_4^+-N concentration with an increase in HRT during all stages.

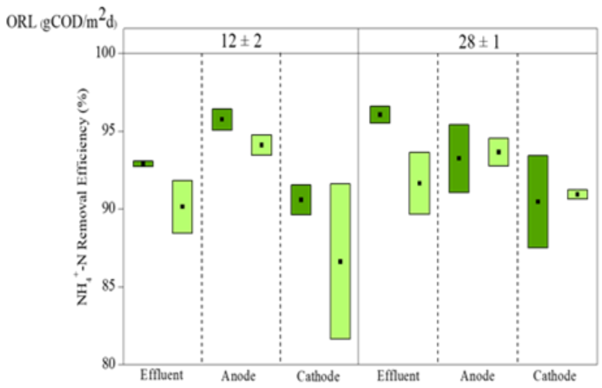

Figure 1. Removal efficiency for NH_4^+-N at different zones of VSSF (■) and VSSF-MFC (■) during different operational stages.

Table 3 shows the power density values, open circuit voltage, internal resistance, and coulombic efficiency obtain during stage I and II for VSSF-MFC. The maximum power density was increase 117% with the increase of the OLR from 12 to 24 COD g/m^2 d. The increase of the substrate concentration had a significant influence ($p<0.05$) in electricity generation in both systems. When working with <1000 mg/L COD concentrations, the organic matter fails to reach the cathodic compartment. This maintains the available dissolved O_2 levels so the reduction reactions can occur and complete the electric circuit.

Table 3. Electric performance of VF-MFC during different operational stages.

Parameter	Unit	System	
		VFP - MFC	
		I	II
Open circuit voltage	mV	357.36	440.44
Internal resistance	Ohms	293.48	200.77
Maximum Power density	mW/m^2	4.75	10.32
Current density	mA/m^2	53.26	97.67
Coulombic efficiency	%	1.80	1.60

References

Doherty, L., Zhao, X., Zhao, Y., Wang, W. (2015), The effects of electrode spacing and flow direction on the performance of microbial fuel cell constructed wetland. Ecological Engineering 79, 8–14.

Oon, Y., Ong, S., Ho, L., Wong, Y., H, Y., Kaur, W. (2015), Hybrid system up–flow constructed wetland integrated with microbial fuel cell for simultaneous wastewater treatment and electricity generation. Bioresource Technology 186, 270–275.

Rabaey, K., & Verstraete, W. (2005), Microbial fuel cells: novel biotechnology for energy generation. TRENDS in Biotechnology, 23, 291-298.

Sonawane, J., Yadav, A., Ghosh, P., Adeloju, S. (2016). Recent advances in the development and utilization of modern anode materials for high performance microbial fuel cells. Biosens Bioelectron. 90, 558-576.

Stefanakis, A. I., & Tsihrintzis, V. A. (2012), Effects of loading, resting period, temperature, porous media, vegetation and aeration on performance of pilot-scale vertical flow constructed wetlands. Chemical engineering journal, 181, 416-430.

Villaseñor, J., Capilla, P., Rodrigo, M.A., Canizares, P., Fernández, F.J. (2013), Operation of a horizontal subsurface flow constructed wetland-microbial fuel cell treating wastewater under different organic loading rates. Water Research. 47, 6731-6738.