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13th IWA Specialized Conference on Small Water and Wastewater Systems

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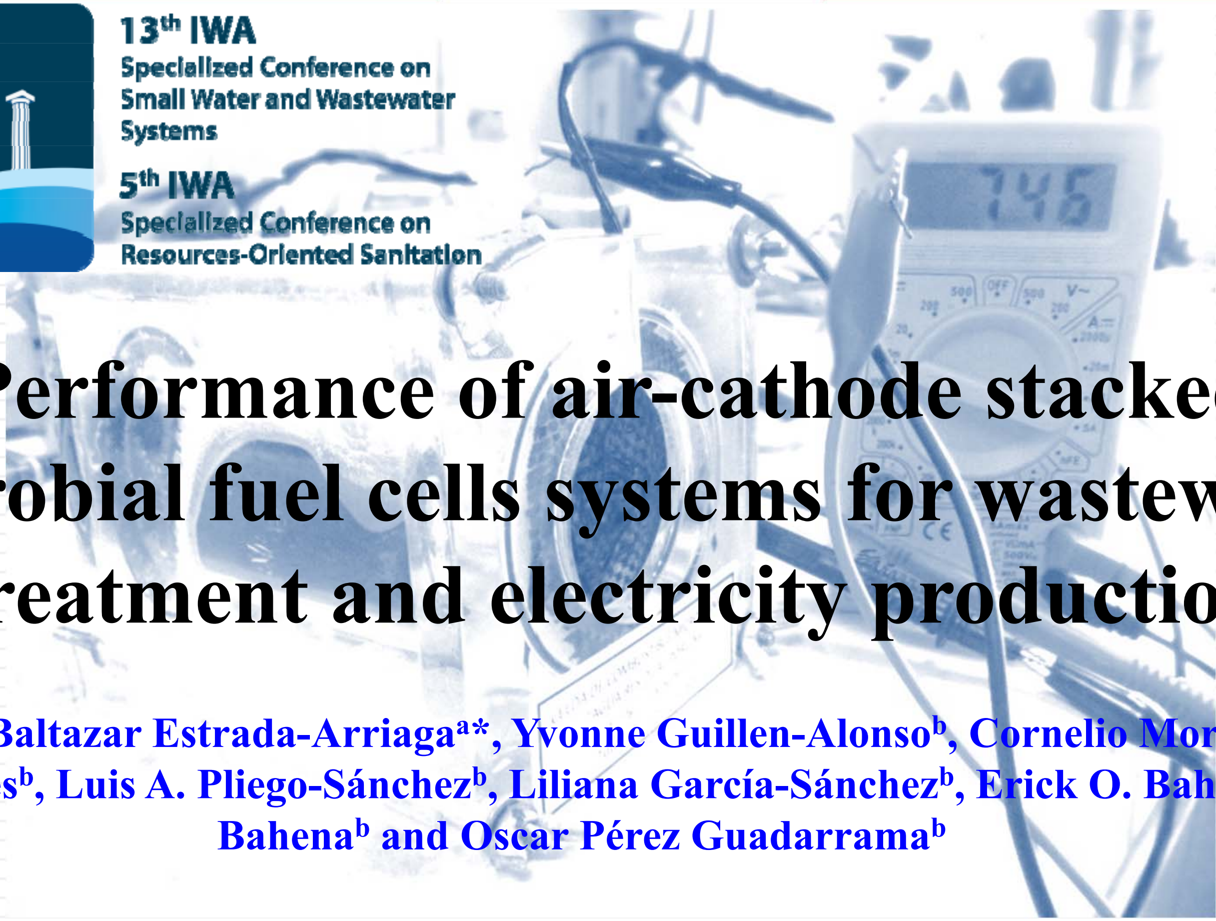

Performance of air-cathode stacked microbial fuel cells systems for wastewater treatment and electricity production

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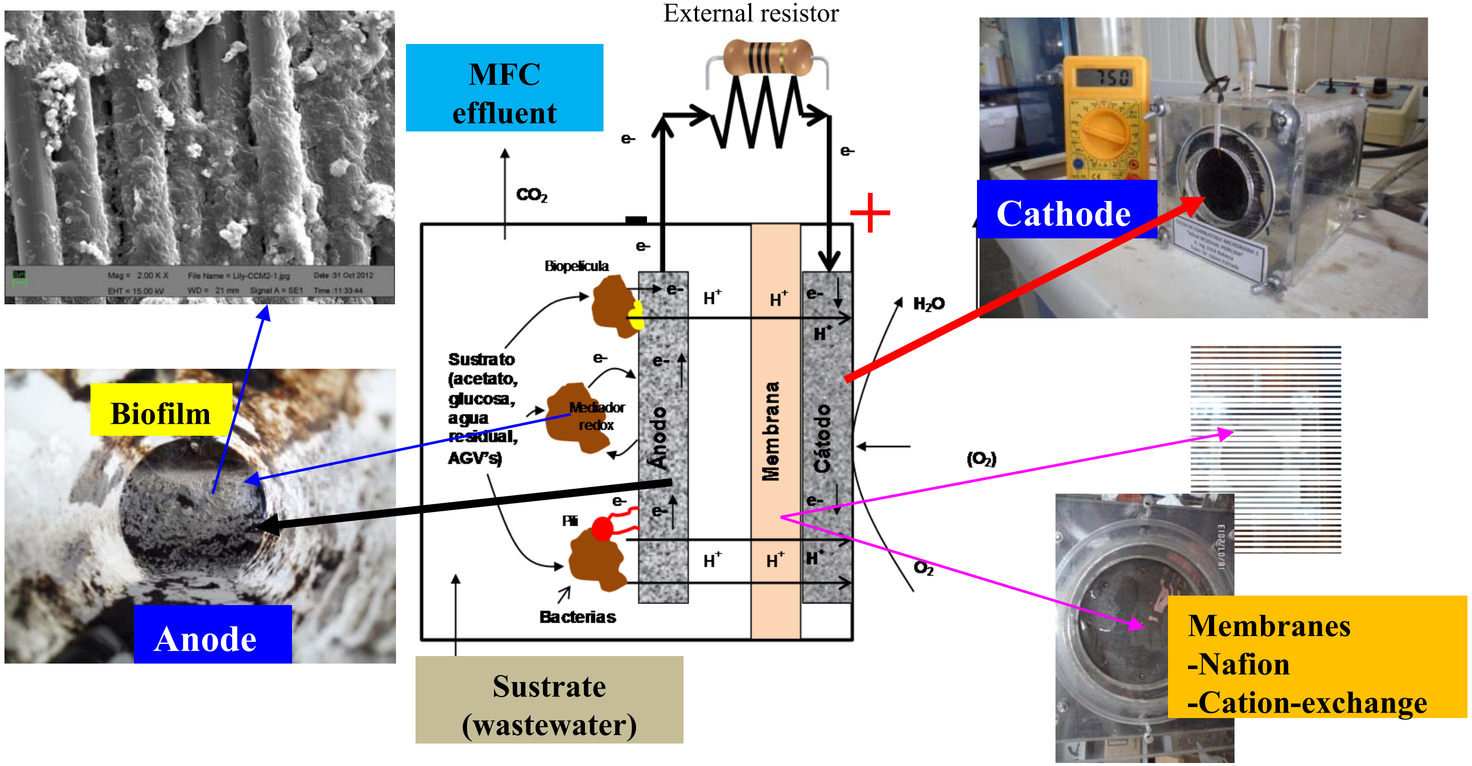
Microbial Fuel Cells (MFCs)

The MFCs are bio-electrochemical systems, capable of generating electricity from the oxidation of organic matter from wastewater treatment and simultaneously the contaminant removal.



Advantages of MFC over current energy generating technologies from organics

* Ambient temperature
* No gas treatment
* No energy input for aeration
* High conversion efficiency
* Application for wide locations and diverse fuels

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Principies of MFC

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- Biochemical degradation – microorganism growth : Oxidation-reduction

  Electrochemistry, Catalyst reaction

  Mass transport, Mixing of substrate
- @ anode, acetate (**substrate**) is oxidized by **bacteria** (catalyst), mixed culture.

$$CH_3COO^- + 4\,H_2O \rightarrow 2\,HCO_3^- + 9H^+ + 8e^- \qquad (E_{an} = -0.296\ V)$$

Electrons produced are transferred to the anode by mediator/shuttles, direct membrane, or nano-wire.

- **Electrons** flow to cathode through a conductive material containing a resistor or operated under a load to produce **electricity**.
- **Protons** diffuse from anode to cathode through cation exchange membrane.
- @ cathode, the electrons are combined with proton and **oxygen** or chemical oxidizer. Diverse bacterial community is working as a catalyst.

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \qquad (E_{cat} = 0.805\ V)$$

2.2 kW/h.m^3 considering that the energy of glucose molecule containing **4.4 kW/h.kg COD** (chemical oxygen demand (COD) of 500 mg/L)

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Voltage productions by MFCs

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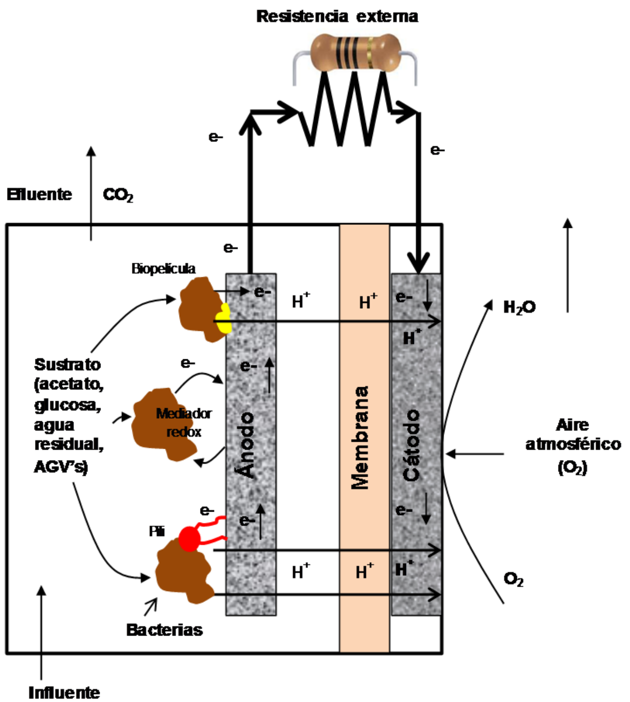
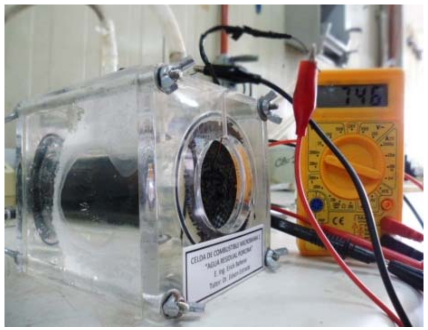
Single chamber air-cathode MFC





- Standard electrode potential, at SC (25 °C, 1 atm, 1 M) = zero, relative to normal hydrogen electrode (NHE)
- **Maximum attainable cell voltage** can be calculated by,

$$E_{emf} = E_{cat} - E_{an}$$

According to **Nernst equation**.

$$E_{emf} = E^0_{emf} - \frac{RT}{nF} ln\left(\frac{[C]^{v_C}[D]^{v_D}}{[A]^{v_A}[B]^{v_B}}\right)$$

Acetate oxidized at anode, oxygen used as e-acceptor at cathode

Anode $2\ HCO_3^- + 9H^+ + 8e^- \rightarrow CH3COO^- + 4\ H_2O$

Cathode $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

$E_{an} = E^0_{an} - RT/8F\ ln([CH_3COO-]/[HCO3-]^2[H+]^9) = -0.296\ V$

$E_{cat} = E^0_{cat} - RT/4F\ ln(1/pO_2[H+]^4) = 0.805\ V$

Oxidation-reduction potentials

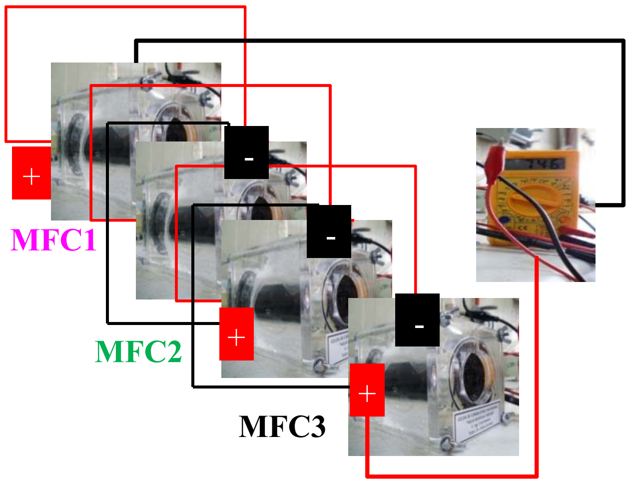
$E_{emf} = E_{cat} - E_{an} = 0.805 - (-0.296) = \mathbf{1.101\ V}$

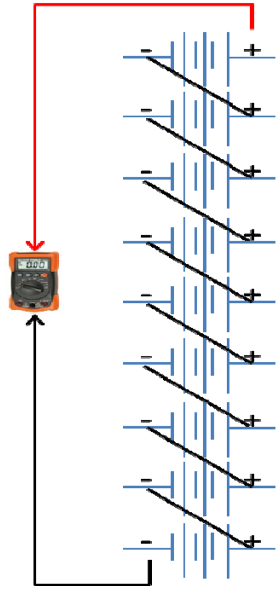
Maximum MFC voltage

Theoretical = **1.1 V**
Open circuit mode (OCV)) = **0.6-0.8 V(without current)**
Real voltage during current generation **< 0.62 V**

Stacked MFC (Multi-electrode MFCs)

A single cell delivering about 0.2-0.8 V (too low for most applications). Just like batteries, individual cells are stacked to achieve a higher voltage and power. This assembly of cells is called a cell stack, multi-electrode or just a stack.





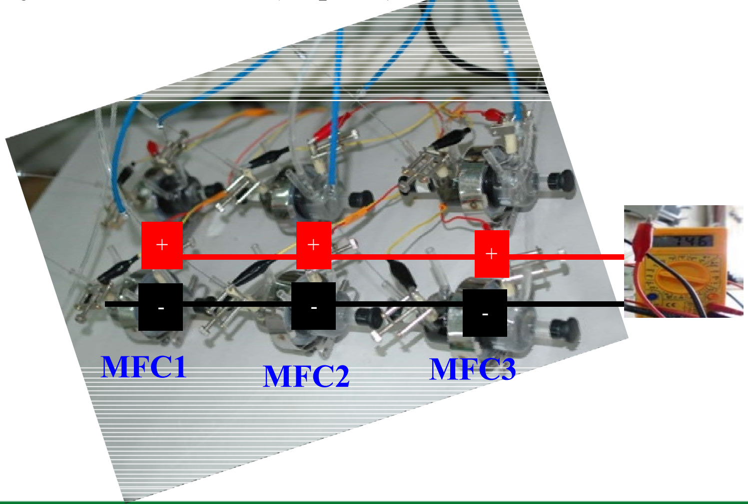
Series connections

Increasing voltage

Stacked $MFC_{Vt} = MFC1_{V1} + MFC2_{V2} + MFC3_{V3} ... MFC\mathit{n+1}_{Vn+1}$

V = voltage (volts)
j = electric current (amperes)

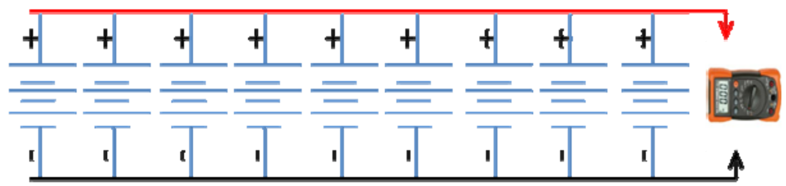
The power density and voltages can be increased when MFCs are stacked in series or in parallel.



Parallel connections

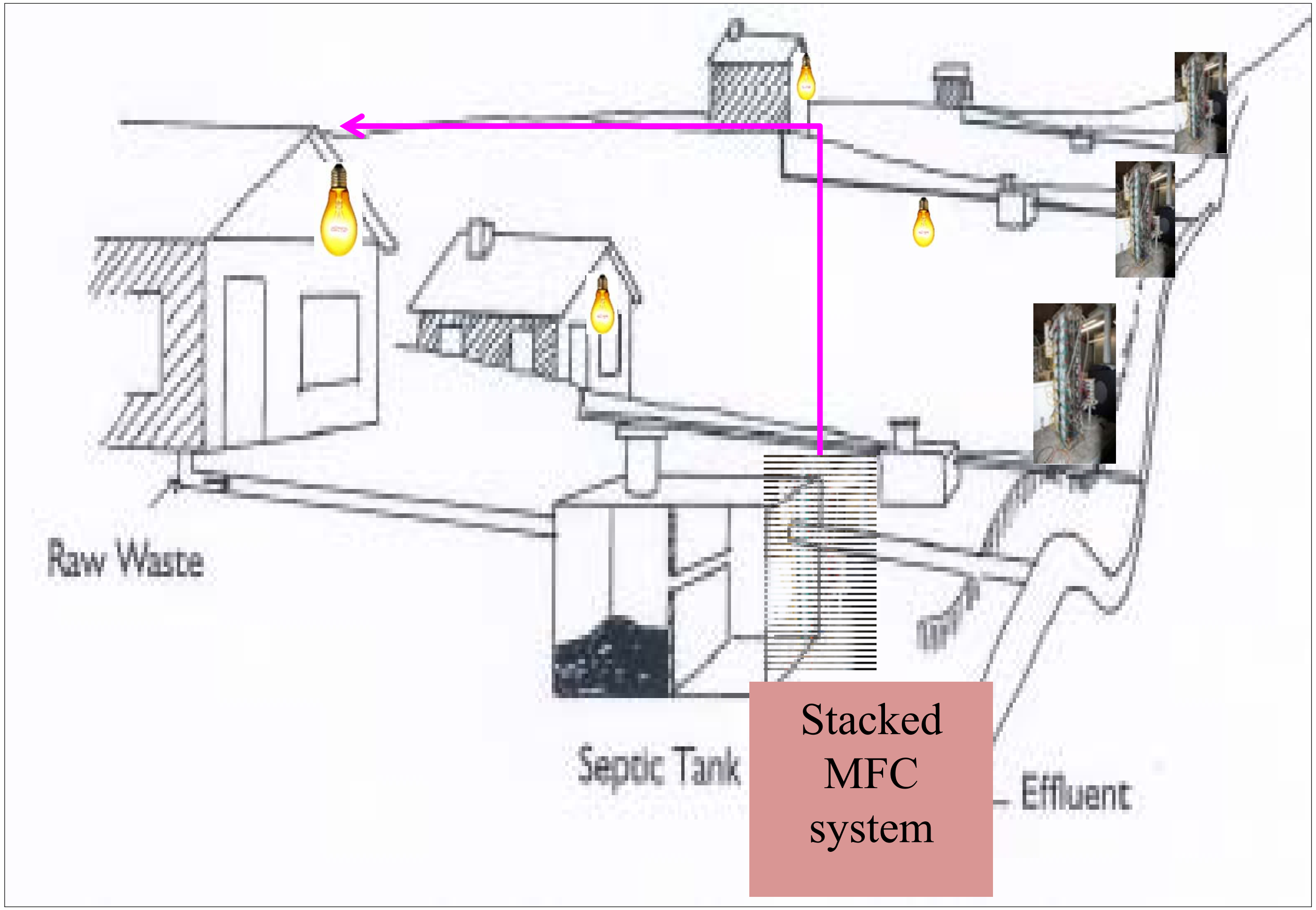
Increasing electric current

(Stacked $MFC_j = MFC1_{j1} + MFC2_{j2} + MFC3_{j3} … MFC\mathit{n+1}_{jn+1}$)



Decentralized wastewater treatment system

MFCs as alternative for wastewater treatment.



New Process-
Microbial
Electrochemical
Technologies

* Removal organic matter
* Electricity direct

Objective

The main objective of this study was to evaluate the performance of two air-cathode stacked MFC systems at different HRT (3, 1 and 0.5 d) during wastewater treatment and electricity production.

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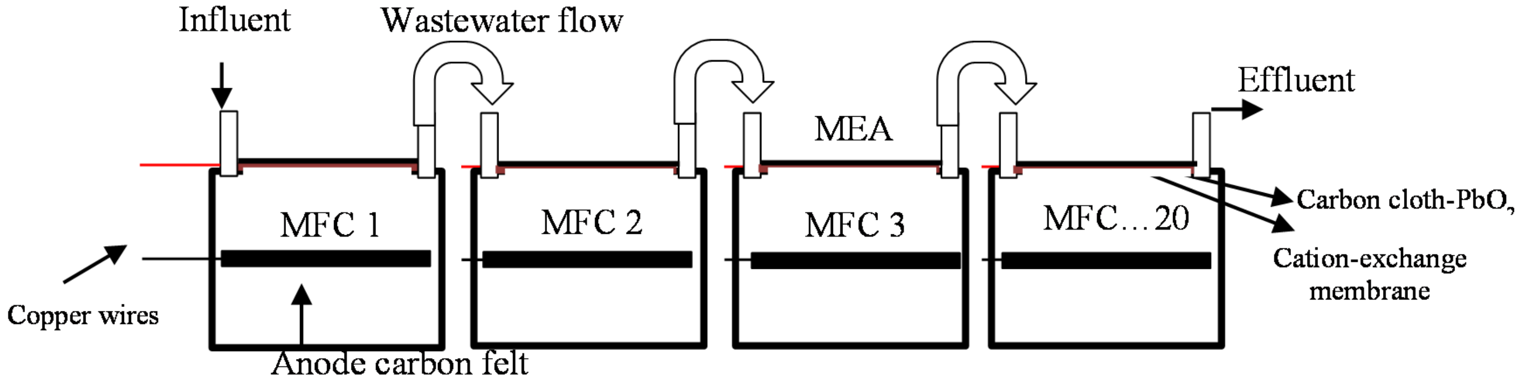
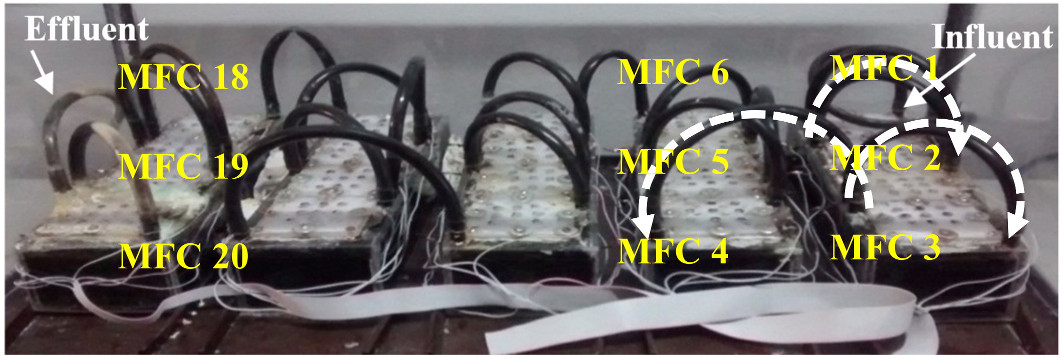
Materials and Methods

Architecture of stacked MFCs

Stacked MFC 1 (un-shared reactor)-shared anolyte



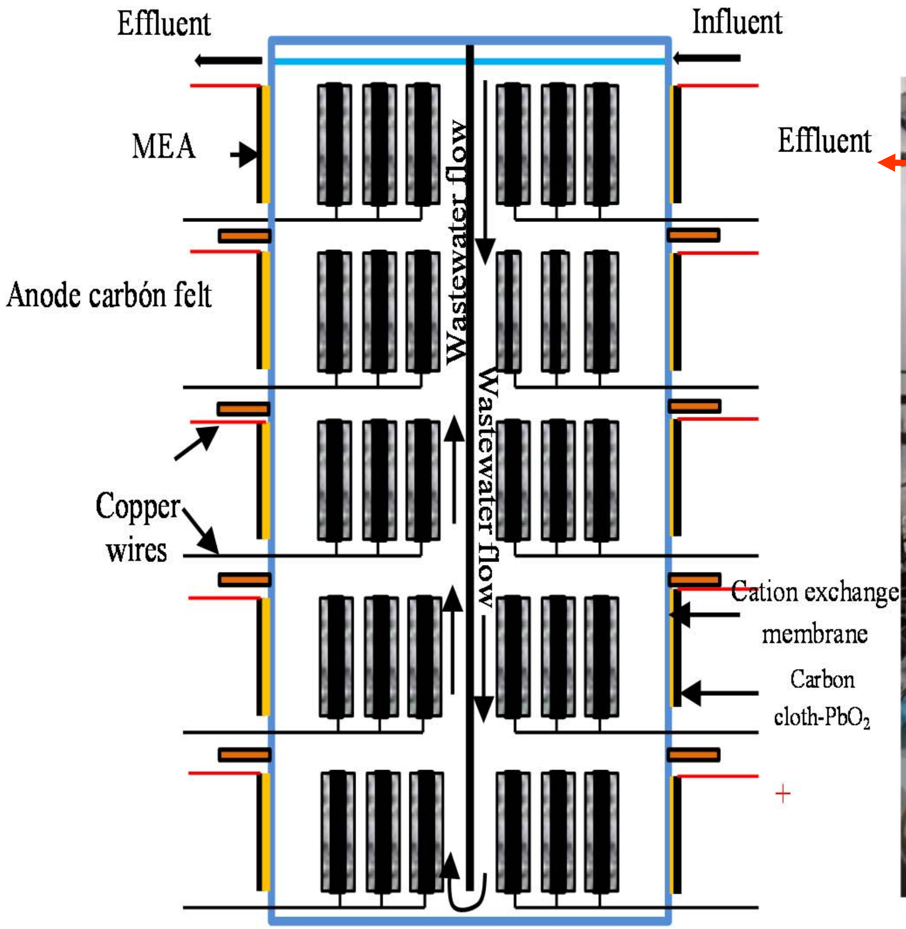


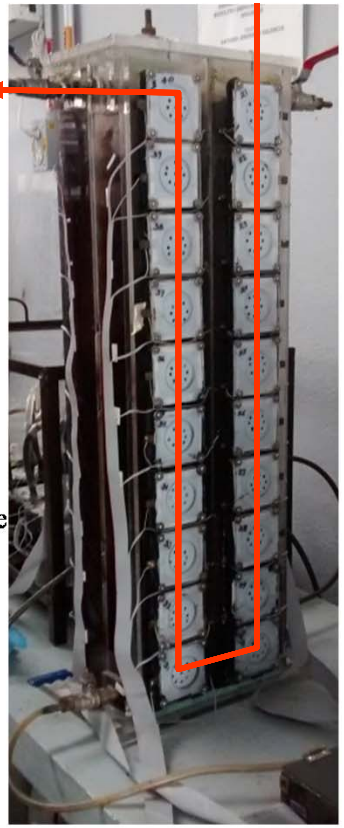
Anode and **cathode** superficial area of *0.0036 m*^{2}

- 20 individual MFC unit (800 mL MFC); Total volume 16 L.
- Single chamber air-cathode MFC
- Stacked MFC 1 was fed in continuous flow cascade mode (flow was transported through of the each MFC compartment

Materials and Methods

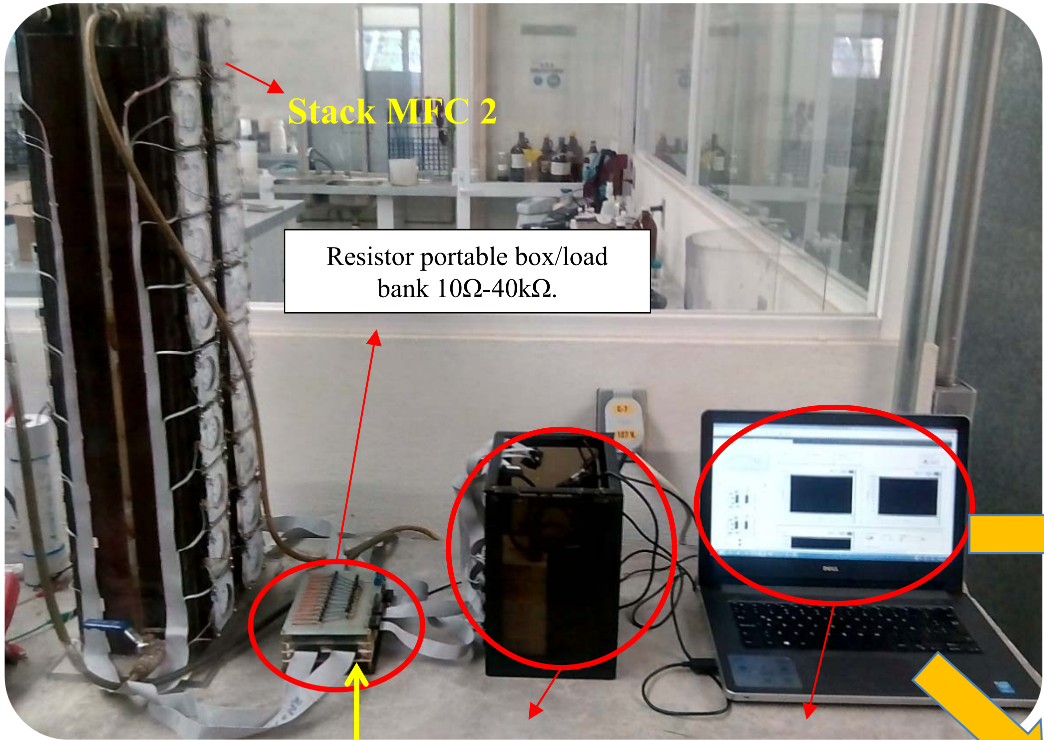
Stacked MFC 2 (shared reactor)-shared anolyte

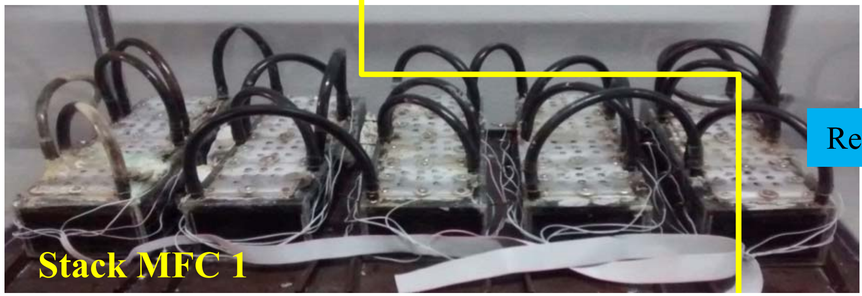




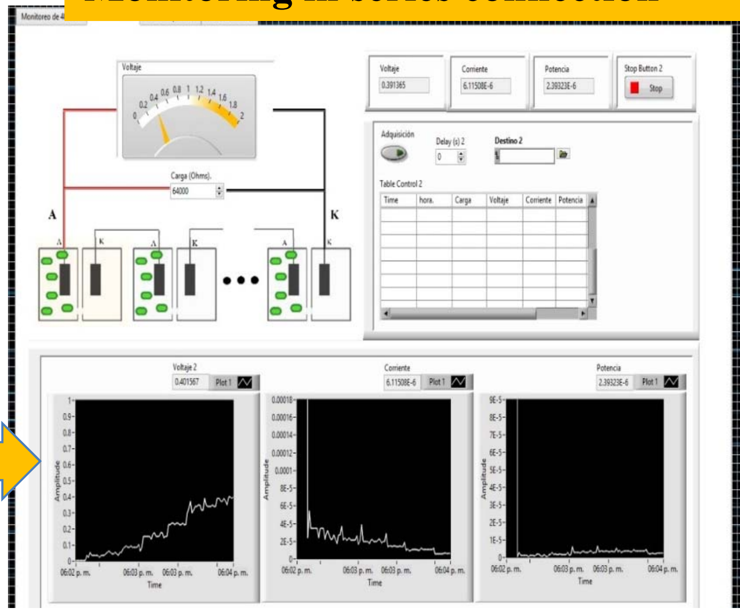
- 40 MFC unit into shared reactor.
- Total volume 16 L.
- Single chamber air-cathode MFC.
- Stacked MFC 2 was fed in continuous flow (not separator between in each cell was used).

Materials and Methods





Monitoring in series connection



Monitoring in individual MFC unit

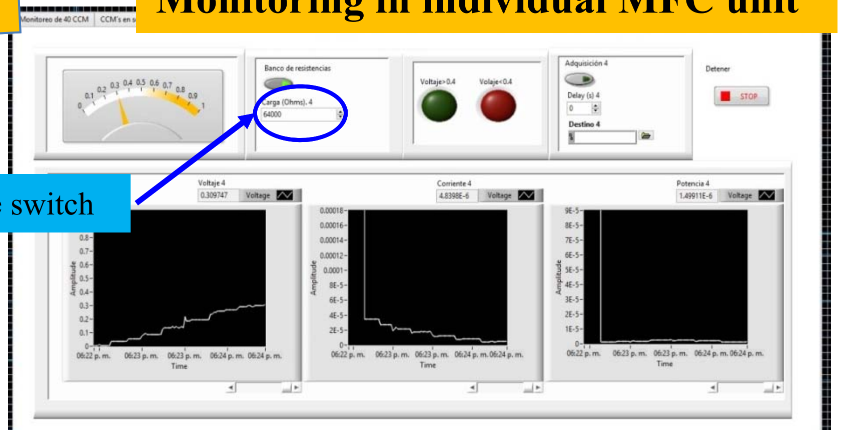


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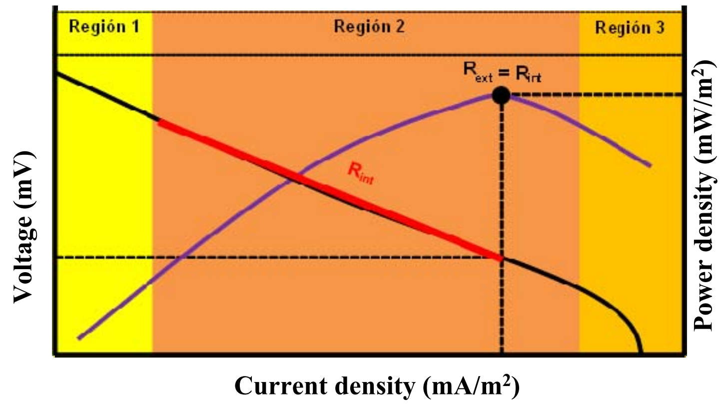
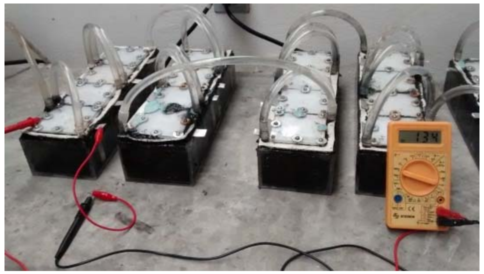
Table 1. Operational conditions

	Open Circuit Mode	Closed Circuit Mode (1,000 Ω)
Biomass aclimatation	HRT 10 d	-
HRT (d)	3, 1 and 0.5	3, 1 and 0.5

Polarization curves



INDIVIDUAL MFC UNIT **SERIES CONNECTION**



$$P = V * I = \frac{V^2}{R_{ext}} = I^2 * R_{ext}$$

$$P^* = \frac{V^2}{aR_{ext}} = \frac{P}{a}$$

$$I = \frac{dq}{dt} = \frac{V}{R_{ext}}$$

$$J = \frac{q}{at} = \frac{1}{a}\left(\frac{q}{t}\right) = \frac{I}{a}$$

COD, TN, and TP were measured using standard methods (APHA, 2005).

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Characteristic of municipal wastewater

COD = 209 ±41 mg/L.

Total Nitrogen (TN) = 38 ±11 mg/L.

Total Phosphorus (TP) = 15 ±3 mg/L.

pH = 6.9-7.5

Total Suspended Solids (TSS) = 200 mg/L

Residential housing

Results

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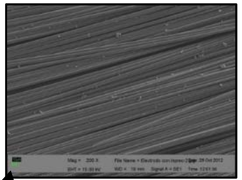
	Stacked MFC 1 (HRT 3, 1 and 0.5 d)	Stacked MFC 2 (HRT 3, 1 and 0.5 d)
Individual MFC unit (OCV)	2-440 mV	263-600 mV
Series connection (OCV)	*20 cells* 580 ±65 mV	*40 cells* 540 ±35 mV
Individual MFC unit (1,000 ohms)	6-50 mV	1-30 mV
Series connection (1,000 ohms)	46 ±28 mV	30 ±8 mV

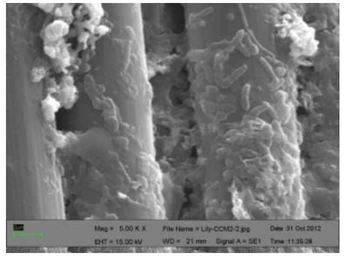
~~$V_{total} = V_{MFC\,1} + V_{MFC\,2} + V_{MFCn+1})$~~

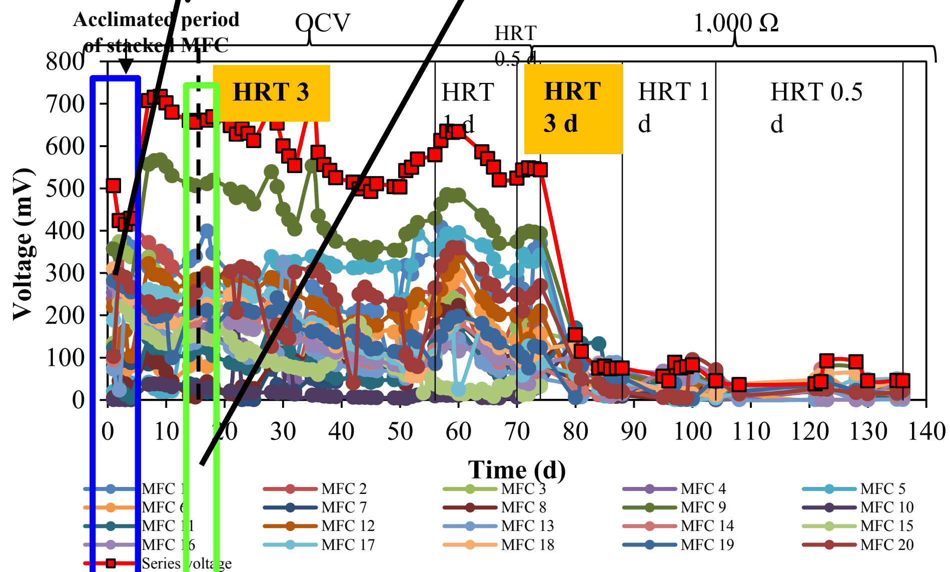
voltage dropped phenomenon

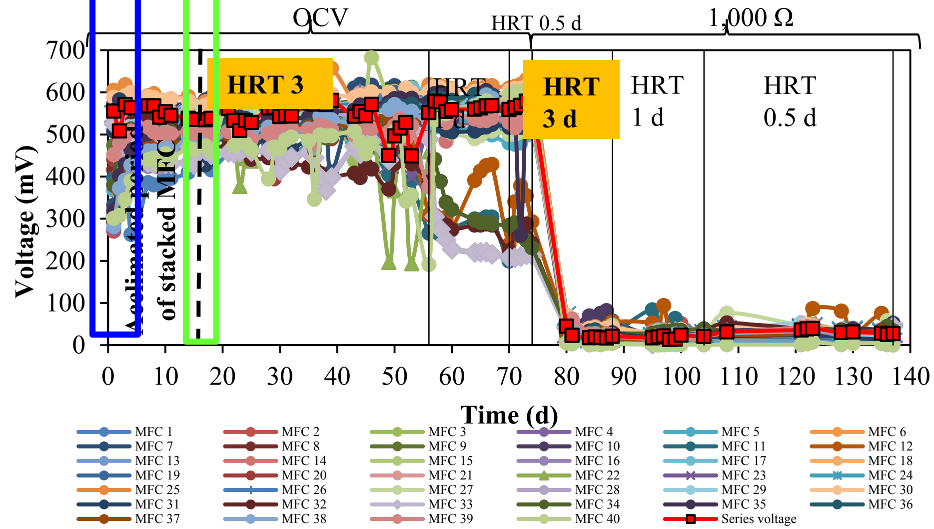
Same anolyte Stacked MFC 1 and 2 ↔ **Shared reactor (Stacked MFC 2)**

ionic cross-conduction between units









Stacked MFC 1

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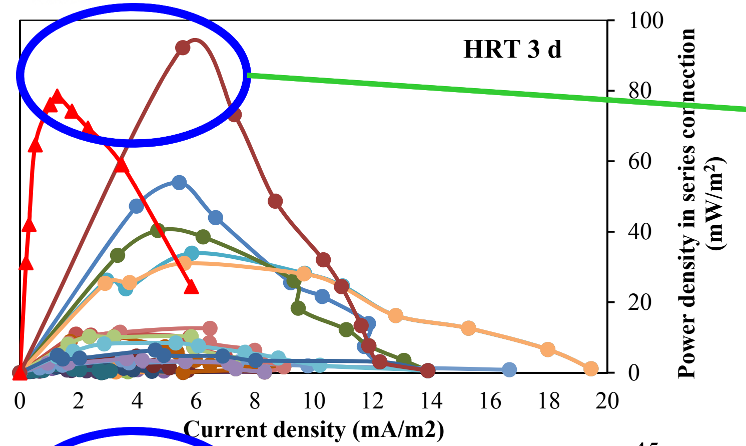
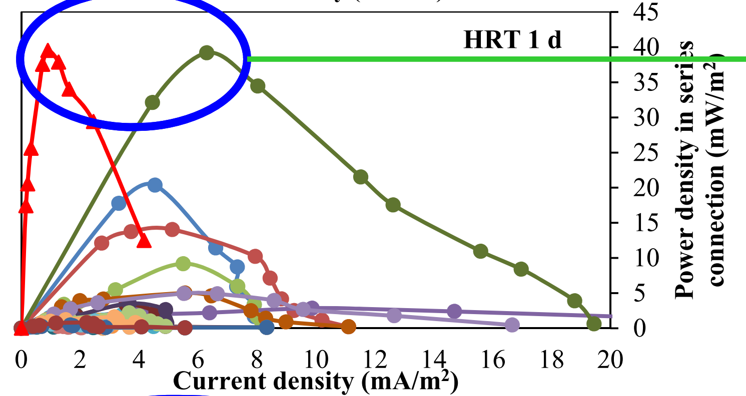
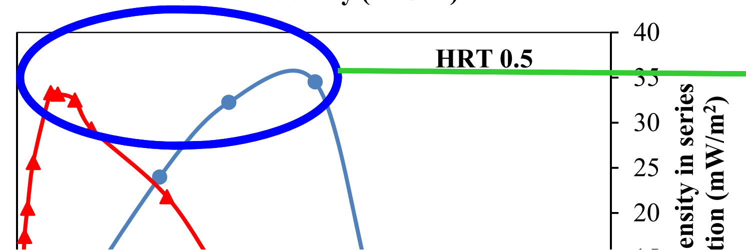
High Power at HRT 3 d



-Individual cell 20 Power = 1,107 mW/m^2
-Series connection Power = 79 mW/m^2



-Individual cell 9 Power = 870 mW/m^2
-Series connection Power = 40 mW/m^2



-Individual cell 1 Power = 430 mW/m^2
-Series connection Power = 33 mW/m^2

ked MFC 2

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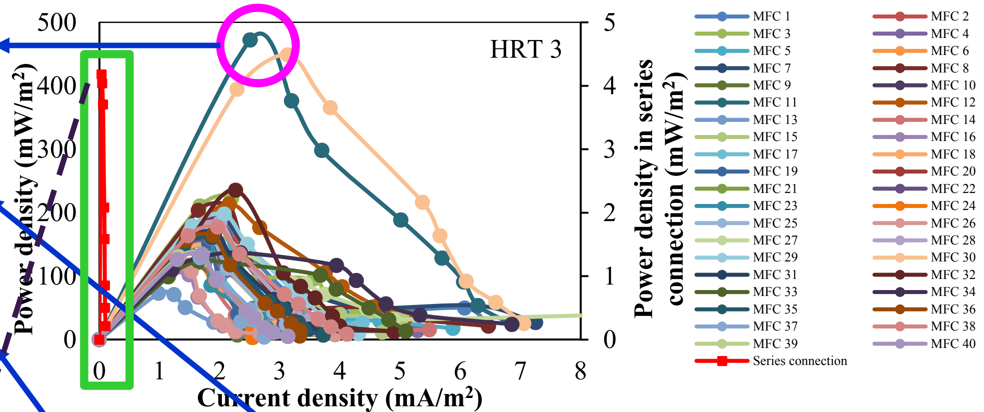
High Power at HRT 3 d

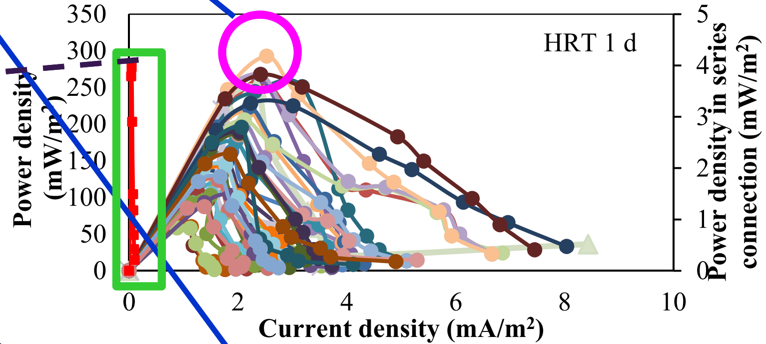
ual cell 11 Power = 472 mW/m²

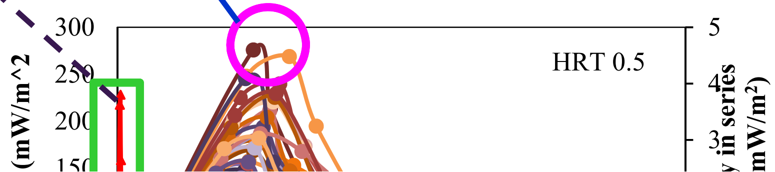
ual cell 34 Power = 292 mW/m²

ual cell 34 Power = 275 mW/m²



connection
3.8-4.2 mW/m²
nt density < 0.1 mA/m²

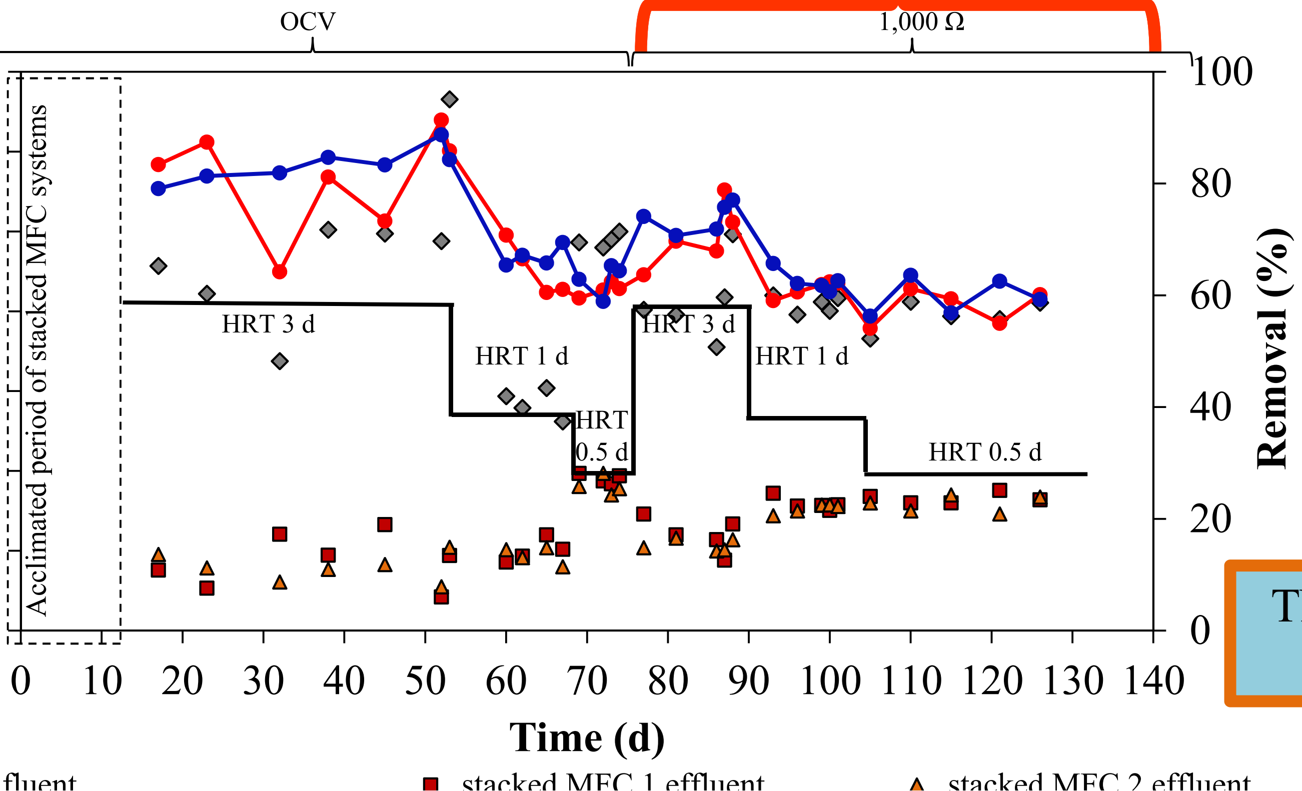




ohmic and activation losses

Removal COD from Stacked MFC 1 and 2 at different HRT (3, 1 and 0.5 d

At closed circuit mode, COD removal were decreased



TN and TP removal were < 47 %

Conclusions

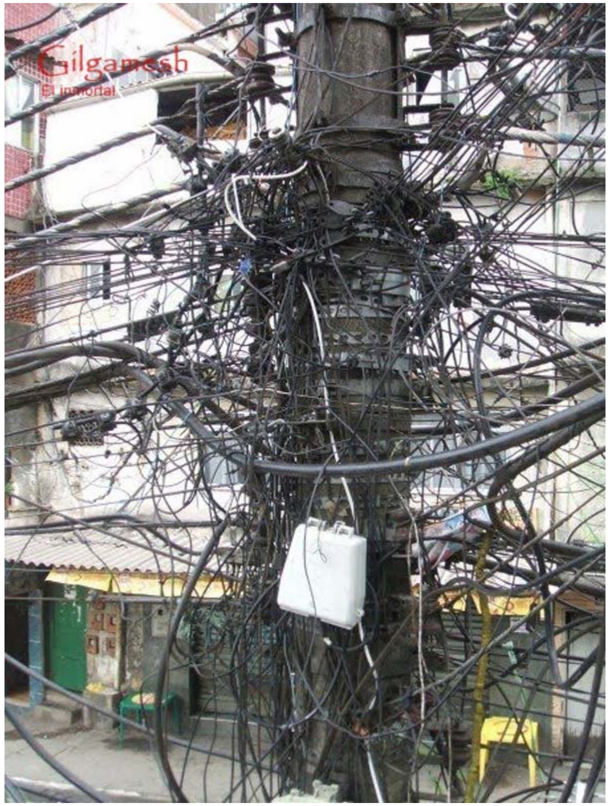
- The two stacked MFC systems tested were not effective for power production in series connection under OCV and closed circuit mode.

- Voltages dropped (voltages reversal) in the two systems were generated due to the architecture of the systems (shared reactor) and the same anolyte in all MFC units.

- The maximum power density in series connection of the stacked MFC 1 was 79 ±0.65 mW/m^2 (current density of 1.3 ±0.4 mA/m^2). For the individual MFC unit (no-series connection), the maximum power density was 1,106 ±1.2 mW/m^2 (current density of 5.5 0.6 mA/m^2) at HRT of 3 d.

- Power production in stacked MFC 2 (4.2 ±0.6 mW/m^2) and the current density (0.04 ±0.006 mA/m^2) were lower compared with the power generated from stacked MFC 1.

- The results showed that the COD removal(up to 84%) were increased when the HRT were increased from 0.5 to 3 d.



Thank you for your attention

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