APPLICATION OF MICROBIAL FUEL CELLS IN WASTEWATER TREATMENT

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AIMS OF THE WORK

The aim of this work is the study of two hypothetical cases in which Microbial fuel cells (MFCs) technology could be used to treat wastewater. The first case is the theoretical implementation of this system in a 6 people home, and the second one is the theoretical integration of this technology into a wastewater treatment plant (WWTP). We shall consider if the process would be economically and energetically profitable in both situations, and last but not less important if possible to scale-up the laboratory experiment to a real life prototype.

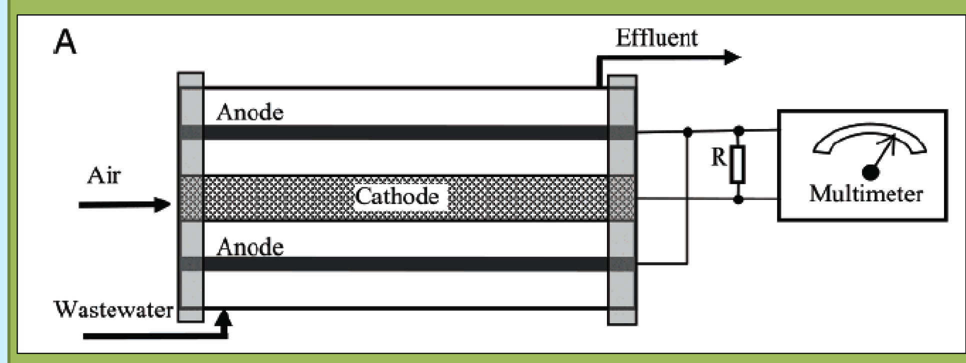
EXPERIMENTAL DATABASE

In order to evaluate the implementation of the system, we need to know the carbonic oxygen demand (COD) of the wastewater and the daily wastewater input. In order to know if the process is energetically profitable, we would use the value of the electrical power consumed in a year by a WWT and a 6 people home.

DATA	6 PEOPLE HOME	WASTEWATER TREATMEN PLANT(3)
DAILY WASTEWATER INPUT	750 Liters (1)	$3 \cdot 10^7$ Liters
AVERAGE DAILY COD INPUT	0,808g/L·day(1)	1.3 g/L·day
ELECTRICAL POWER CONSUMED IN A YEAR	5600kWh(2)	3240000kWh

MFC PROTOTYPE

In this paper, we use a single chamber microbial fuel cell (4). It contains 8 graphite electrodes rods (anode) arranged concentrically around a Permeable Proton Exchange Membrane (PEM) PEM. The cathode is situated in the middle of the bioreactor, under the PEM and it is in direct contact with the air

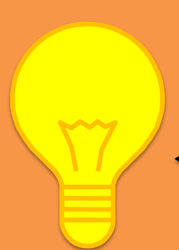


MFC laboratory prototype is 15cm long by 6.5 cm diameter with an empty bed volume of 388mL. The cathode (2,5 cm diameter) is in direct contact with the air.

OPERATION DATA	Retention time: 33 h	Voltage: 0.5V
COD removal: 80%	Coulombic efficiency: 12%	Electrical power achieved: 26mW/m²

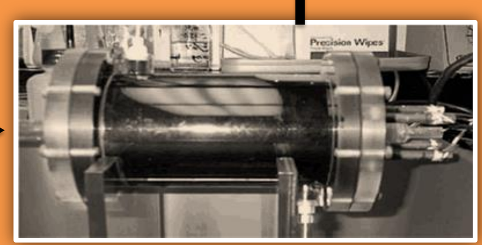
Application of MFC in a 6 People home

ANNUAL ELECTRICAL CONSUME 5600kWh



< 1% of the electrical power consumed by the house in a year is recovered

GENERARATION OF **47.3 kWh** IN A YEAR



MFC(4)

Daily wastewater input	750L
Average COD	0,808g/L·day

Table1 Calculation of the energy produced annually by a MFC during a year in a 6 people home system.

Calculation of the electrical charge in coulombs generated per hour in a 6 people home.

$$\frac{750\ L}{24\ h} \times \frac{0.808\ g\ DQO}{L} \times \frac{1\ mole\ COD}{30\ g} \times \frac{4\ moles\ é}{1\ mole\ COD} \times \frac{6.022 \cdot 10^{23}\ é}{1\ mole\ é} \times \frac{1\ coloumb}{6.024 \cdot 10^{18}} = 3.25 \cdot 10^5\ {}^C/_h$$

The Coulombic efficiency is 12%

$$3.25 \cdot 10^5\ {}^C/_h \times \frac{12}{100} = 3.9 \cdot 10^4\ {}^C/_h$$

We have to convert the C/h to C/s in order to work out the intensity:

$$\frac{3.09 \cdot 10^4\ C}{1\ h} \times \frac{1h}{3600s} = 10.83\ {}^C/_s = 10.83\ A$$

Once we have the intensity, with the voltage we can calculate the power.

$$P = Intensity \times voltage$$
$$P = 10.83\ A \times 0.5V$$
$$P = 5.416W$$

We convert W to KWh

$$5.416W \times \frac{1\ kW}{1000W} \times 8760h = 47.3kW \cdot h\ in\ a\ year$$

A 6 people home have an annual consume of 5600kWh

$$\frac{47.3 \times 100}{5600} = 0,84\%$$

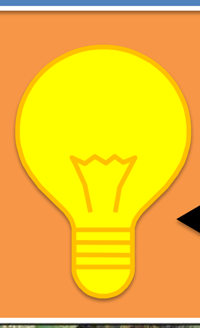
The electrical power produced by the MFC system correlates with the 0, 84% of the power consume by the home.

(*) To calculate COD molecular weight, we consider the chemical formula CH_2O

We can conclude that the system is not cost effective, only 0,84% of the electrical power consumed by the house in a year is recovered, so the implementation in this situation is not profitable.

Application of MFC in a Wastewater treatment plant

ANNUAL ELECTRICAL CONSUME 3240000kWh



94.22% of the electrical power consumed by the WWTP in a year is recovered

GENERARATION OF **3052860 kWh** IN A YEAR

MFC (4)

Daily wastewater input	$3 \cdot 10^7$L
Average COD	1.3 g/L·day

Table 2 Calculation of the energy produced annually by a MFC during a year in a wastewater treatment plant.

Calculation of the electrical charge in coulombs generated per hour in a Wastewater Treatment Plant

$$\frac{3.0 \cdot 10^7\ L}{24\ h} \times \frac{1.3\ g\ DQO}{L} \times \frac{1\ mole\ COD}{30\ g} \times \frac{4\ mols\ e}{1\ mol\ COD} \times \frac{6.022 \cdot 10^{23}\ é}{1\ mol\ é} \times \frac{1\ coloumb}{6.024 \cdot 10^{18}\ é} = 2.09 \cdot 10^{10}\ {}^C/_h$$

The Coulombic efficiency is 12%

$$2.09 \cdot 10^{10}\ {}^C/_h \times \frac{12}{100} = 2.51 \cdot 10^9\ {}^C/_h$$

We have to convert the C/h to C/s in order to work out the intensity:

$$\frac{2.51 \cdot 10^9\ C}{1\ h} \times \frac{1h}{3600s} = 6.97 \cdot 10^5\ {}^C/_s = 6.97 \cdot 10^5 A$$

Once we have the intensity, with the voltage we can calculate the power.

$$P = Intensitat \times voltage$$
$$P = 6.97 \cdot 10^5 A \times 0.5V$$
$$P = 3.485 \cdot 10^5 W$$

We convert W to KWh

$$3.485 \cdot 10^5 W \times \frac{1\ kW}{1000W} \times 8760h = 3052860kW \cdot h\ in\ a\ year$$

The wastewater treatment plant has a annual consume of 3240000kWh

$$\frac{3052860 \times 100}{3240000} = 94.22\%$$

The electrical power produced by the wastewater treatment plant using a MFC system is a 94, 22% of the energy consumed by this plant during a year.

(*) To calculate COD molecular weight, we consider the chemical formula CH_2O

As we see in **Table 2**, in this case we can conclude that **the system is cost effective**, 94,22% of the electrical power consumed by a WWTP in a year is recovered, so we should be considering the implementation of this particular method.

We are going to calculate, in a hypothetical way, the dimensions which should have the bioreactor in order to achieve such energy production.

Table 3 Scaling up the dimensions of the MFC prototype in a wastewater treatment plant

The hydraulic retention time is 33h for a removal of the 80% of the COD. If every day $3 \cdot 10^7$L of wastewater enter in the Water Waste Treatment Plant, how many m³ should have the bioreactor?

$$\frac{30000m^3}{24h} \times 33h = 41250m^3$$

How many m² should have the anode surface if the production of power is 0,026W/m² and the power generated is $3,485 \cdot 10^5 W$?

$$3,485 \cdot 10^5 W \times \frac{1m^2}{0.026W} = 1,34 \cdot 10^7 m^2$$

If we scale-up ten time (10x) the thickness of the bioreactor. How long should it be?

Total diameter: 65 cm→r_1=32,5cm
Diameter of the cathode: 25cm →r_2=12cm

We have to find the length of the bioreactor, in order to do that, we have to know which volume of water can be contained in the bioreactor. We should also subtract the volume occupied by the cathode to the total volume (in m³). Finally we will be able to know how long has to be our bioreactor to fit the daily volume (41250L).

$$(\pi \cdot r_1^2 \cdot lenght) - (\pi \cdot r_2^2 \cdot lenght) = total\ volume\ in\ a\ day$$
$$length \cdot \pi \cdot (r_1^2 - r_2^2) = total\ volume\ in\ a\ day$$

$$lenght = \frac{41250m^3}{0,09m^3} = 458Km$$

As we see in **Table 3**, it would be impossible to build a bioreactor of these dimensions (458 km length and 65 cm diameter). We should modify our configuration in order to obtain dimensions that could be applied in a real situation. We realize that increasing the radius would reduce considerably the length. Let suppose we build, 50 tubes of 100 meters each one, in **Table 4** we calculate the dimensions of our new tube in order to contain the equivalent volume of water.

Table 4 Diameter calculation of the prototype if we build 50 tubes of 100 meters length.

If we built 50 bioreactor tubes of 100 meters length each one, which should be the diameter of each tube?

$$length \cdot (r_1^2 - r_2^2) = total\ volume$$
$$\pi \cdot (r_1^2 - r_2^2) = \frac{total\ volume}{lenght}$$
$$\pi \cdot (r_1^2 - r_2^2) = \frac{41250}{5000}$$
$$(r_1^2 - r_2^2) = \frac{8,25}{\pi}$$

We substitute in the formula r_1

$$r_1 = 2.6 \cdot r_2$$

$$((2.6 \cdot r_2)^2 - r_2^2) = \frac{8,25}{\pi}$$

r_2 = 0,66m (66cm)→ diameter: 172,8 cm
r_1= 1,728m (172,8cm)→ diameter: 345,6cm

In order to have a realistic scale-up dimension of the bioreactor, we could build 50 tubes of diameter 345,6 centimeters and the cathode diameter should be of 172,8 cm. Each tube would be 100 meters long.

CONCLUSIONS

Microbial fuel cells are a novel technology that needs to be improved. In this study, when we apply theoretically the technology in a 6 people home, the results were lower than expected. Less than a 1% of the electricity power consumed by this home could be recovered.

On the other hand, when we apply the technology in a WWTP, the 94,22% of the energy consumed annually by the WWTP is recovered while removing an 80% of the COD. The problem was that in a scale-up prototype, the dimensions obtained were higher than expected due to the huge hydraulic retention time needed by the system (33 hours) .

There is a need for more in situ (scale-up) experiments to examine the technical viability of the MFC technology and improve the systems.

REFERENCES

(1) Taure Menéndez, J. (2001). ¿Cuánto "contamina" realmente un habitante equivalente? *Tecnología Del Agua*.

(2) (INE), Instituto nacional de estadística (n.d.). www.comparatarifasenergia.es.

(3) Ajuntament de Sabadell", A. de. (n.d.). http://ca.sabadell.cat/

(4) Liu, H., Ramnarayanan, R., & Logan, B. E. (2004). Production of electricity during wastewater treatment using a single chamber microbial fuel cell. *Environmental Science & Technology*, *38*(7), 2281–5.