Using household food waste as a source of energy in a single-chamber microbial fuel cell

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Food Wastes

- **Uneaten food and food preparation leftovers from residences, commercial establishments and institutional sources.**

- **Household food wastes (HFW): meal leftovers and food preparation residues generated at residences .**

- **Ideal substrate for bioconversion to various high added-value products via microbiological processes, due to their high content in soluble Chemical Oxygen Demand (COD) and the necessary nutrients.**

Food Wastes used in this study

- Collected at municipality level twice a week from 230 houses of the Municipality of Halandri, Greece. Upon collection, HFW was subjected to simultaneous heat-drying at 95-98^{o}C and shredding.

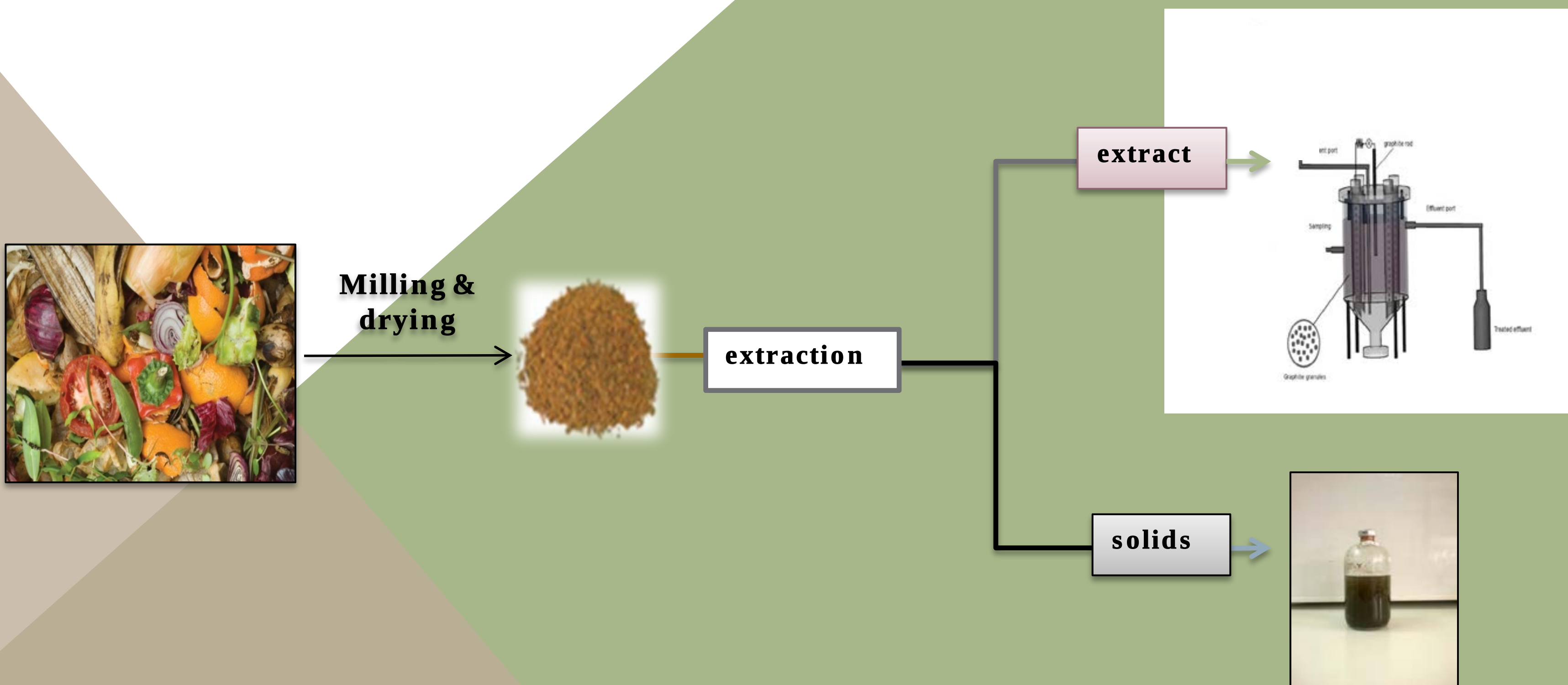
230 RESIDENTS

120 L bins

Household Food Waste (HFW)

Aim of the study :

✓TO ASSESS THE POSSIBILITY OF VALORISATION OF TYPICAL HFW VIA ITS BIOCONVERSION TO A) ELECTRICITY THROUGH A MICROBIAL FUEL CELL (MFC) AND B) METHANE PRODUCTION THROUGH ANAEROBIC DIGESTION (AD)



MFC technologies

- A MFC is a bioreactor that converts the energy stored in chemical bonds in organic compounds directly into electricity through catalytic reactions of microorganisms under anaerobic conditions

Advantage:
- Bio-energy production
- Waste(water) treatment

- Provides possible opportunities for practical applications *(Rabaey and Verstraete, 2005):*

MFC technologies

- A MFC is a bioreactor that converts the energy stored in chemical bonds in organic compounds directly into current through catalytic reactions of microorganisms under anaerobic conditions *(Du et al 2007).*

Advantage:
- Bio-energy production
- Wastewater treatment

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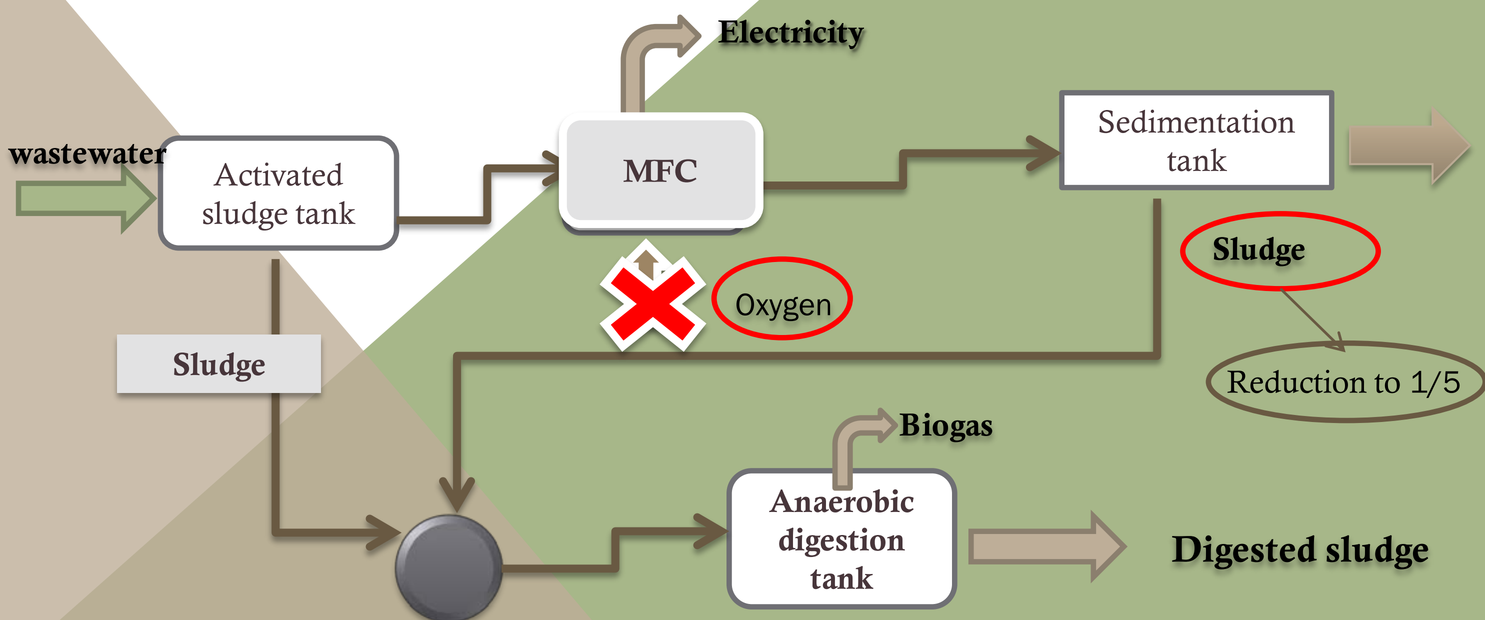
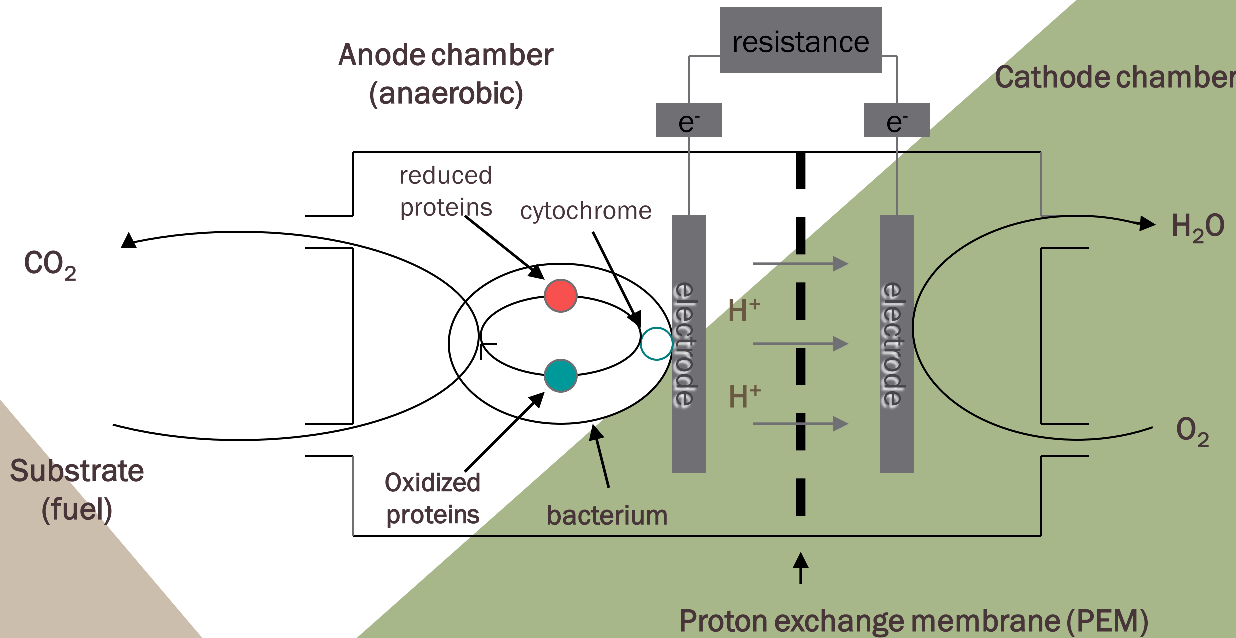


WWTP

MFC technologies



The electrochemical reactions which are carried out in a MFC using e.g. glucose as fuel are :

Anodic reaction : $C_6H_{12}O_6 + H_2O \rightarrow 6CO_2 + 24e^- + 24H^+$

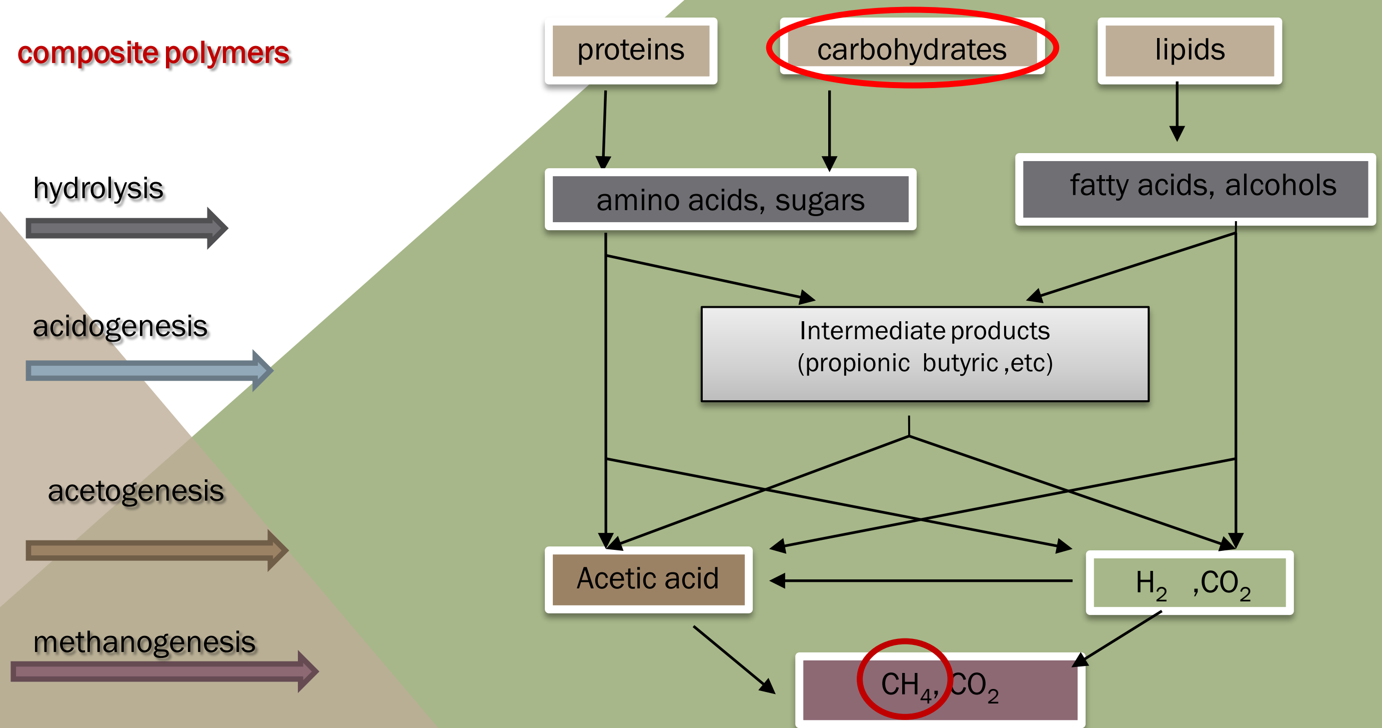
Cathodic reaction: $O_2 + 4e^- + 4H^+ \rightarrow 2H_2O$

Anaerobic digestion

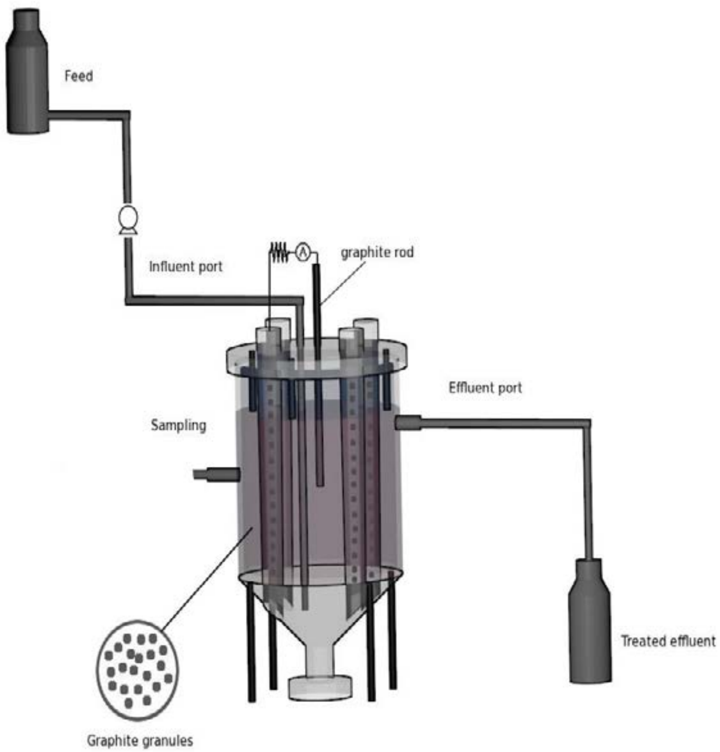
- Anaerobic digestion is one of the most important biochemical processes for biomass conversion to methane

- CH_4 and CO_2 are produced from organic substrates via mixed microbial consortia under anaerobic conditions

$$\text{Organic substrate} + H_2O \longrightarrow CH_4 + CO_2 + NH_3 + \text{new cells}$$

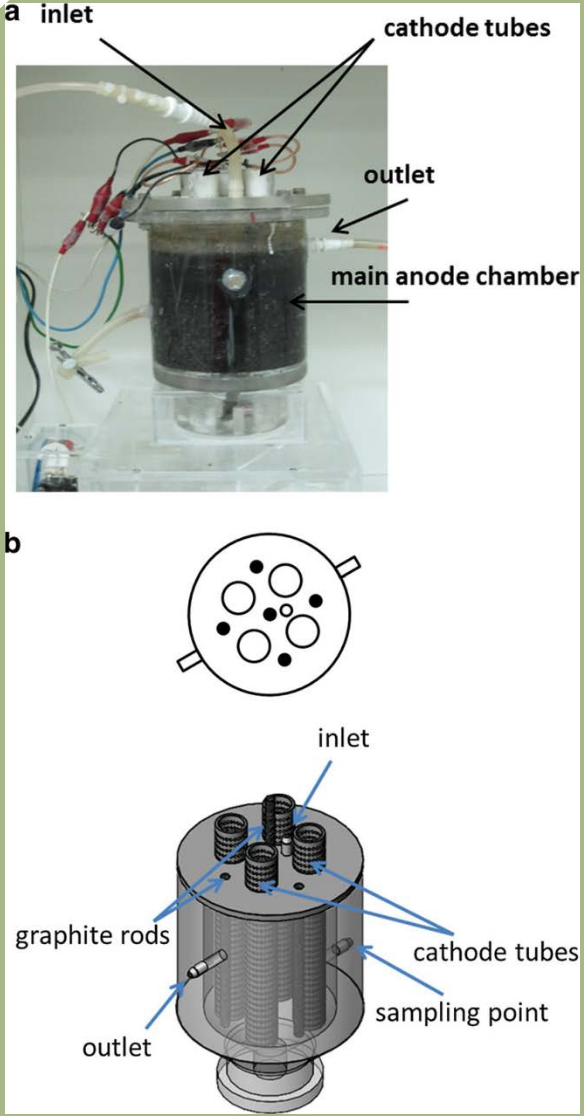


Single chamber MFC



<u>Anode</u>
graphite granules

<u>Cathode</u>
GORE-TEX ® cloth
catalyst: MnO_2



Biochemical Methane Potential (BMP) tests

Serum vials of 160 mL

T= 35^{o}C

Headspace

Biogas measurement

Methane content

- **Inoculum:** Anaerobic sludge from the anaerobic digester of Athens wastewater treatment plant
- 20 % (v/v) inoculum + 2 g VS of feedstock /L + trace elements

the solid fraction obtained after the extraction

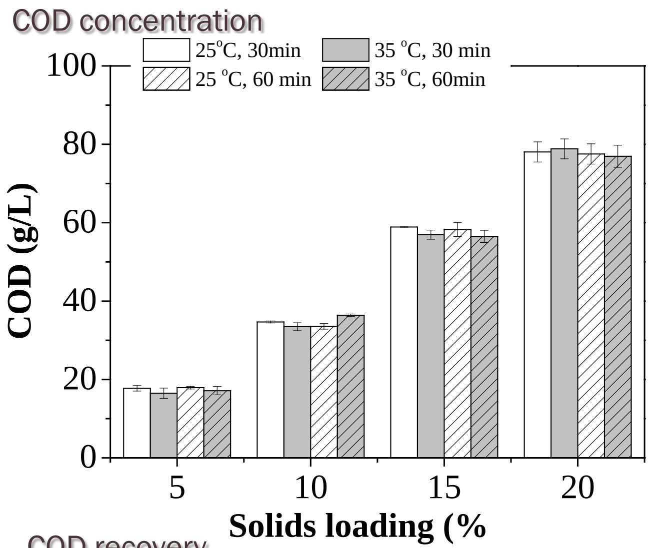
RESULTS
Extraction of the HFW

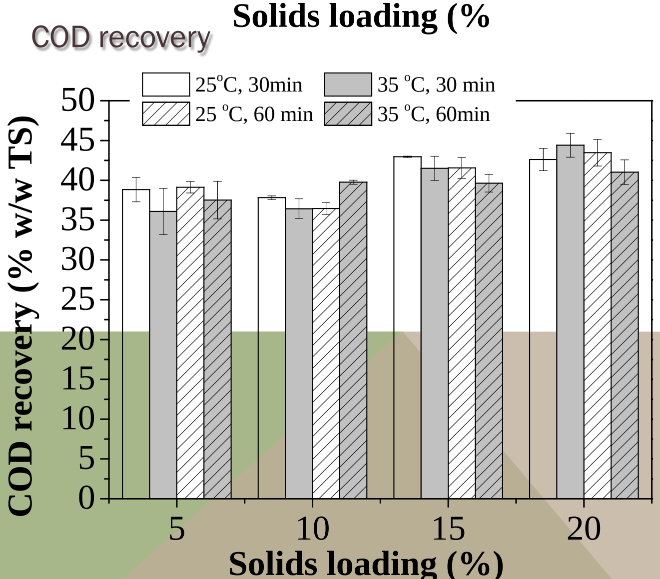
Composition of HFW

Characteristic	Value
Total Solids (%)	91.28±0.75
Volatile Solids (%)	92.34±0.73
Total Carbohydrates (g/g TS)	0.43±0.03
Soluble Carbohydrates (g/g TS)	0.21±0.01
Starch (g/g TS)	0.16±0.01
Cellulose (g/g TS)	0.10±0.01
Total Kjeldahl Nitrogen (g/ 100g TS)	1.63±0.17
Proteins (g/100g TS)	10.17 ± 1.06

Promising substrate for the production of bioenergy

Optimization of extraction process





Parameter tested	values
Solids loading (%)	5, 10, 15, 20
Time of extraction (min)	30, 60
Temperature (°C)	25, 35

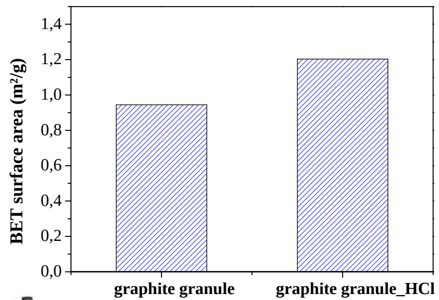
- ✓ no significant differences in neither concentration nor yields of COD
- ✓ the mean yield of COD was estimated to be 40 ± 1 %, indicating that the whole amount of the soluble COD contained in the HFW can be recovered even using the lowest temperature and extraction time and the highest solids loading.

Extraction protocol

20 % wTS/v, 25 °C, 30 min

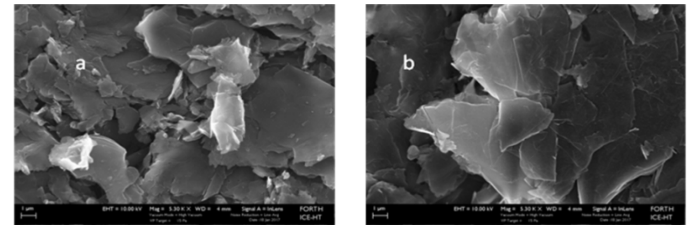
MFC operation

Treatment of granules with 32 % HCl

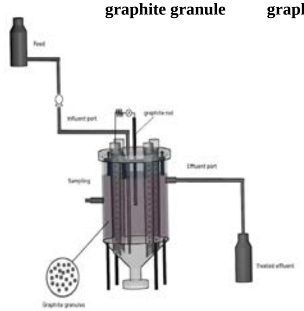


increase by 27%
(1.2032 ± 0.0091 m^2/g)
BET analysis

SEM images from a) untreated and b) treated with HCl graphite granules



T= 28°C
R=100 Ω
V_{total} = 1072 mL
$V_{working}$ = 450 mL



- ✓Glucose (acclimation)
- ✓Glucose
- ✓ HFW

Glucose

Effect of HRT (38, 30,24,18,14,9,18 h)

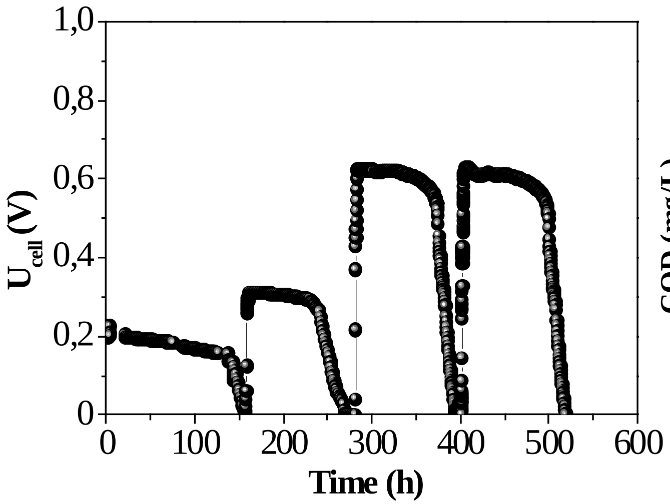
Medium: Carbon source → Glucose (787 ± 39 mg COD/L)
Nutrients: $Na_2HPO_4 * 2H_2O$: 3.4472 g/L, NaH_2PO_4: 3.668 g/L, $NaHCO_3$: 5 g/L, KCl: 0.16 g/L+ trace elements

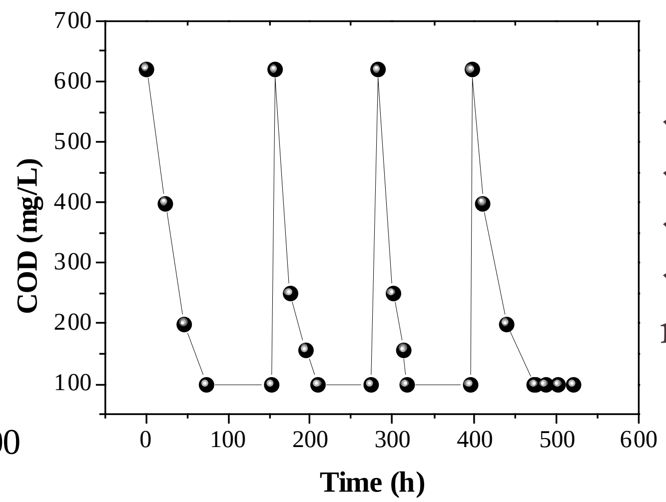
Extract of HFW

Effect of organic loading

Medium: Carbon source → HFW (639 ± 30, 1232 ± 52 , 2130 ± 69 mg COD/ L)
Nutrients: $Na_2HPO_4 * 2H_2O$:3.4472 g/L, NaH_2PO_4: 3.668 g/L, $NaHCO_3$: 5 g/L, KCl: 0.16 g/L
HRT: 18 h

MFC acclimation





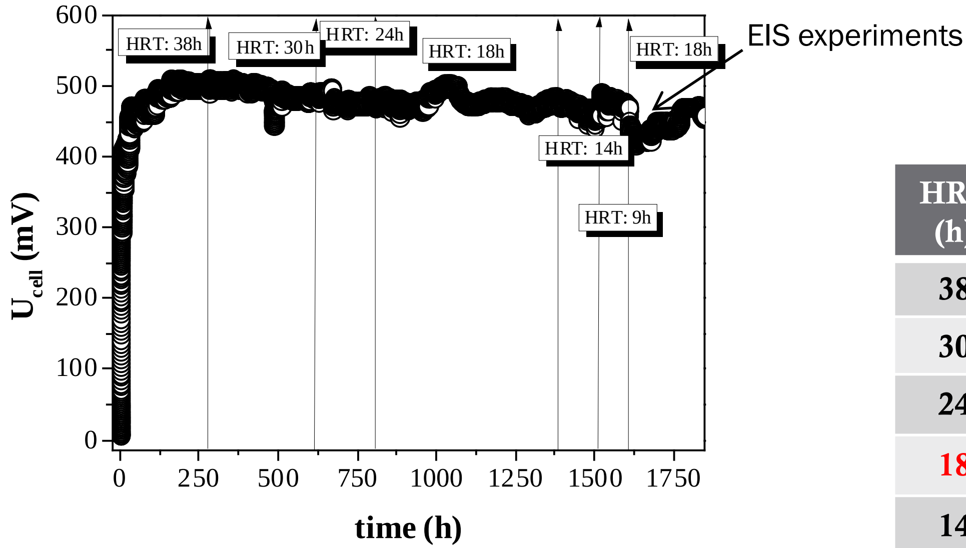
- ✓ Glucose (680 ± 32 mg/ L)
- ✓ Batch mode
- ✓ R=100 Ω
- ✓ 10% v/v inoculum of methanogenic sludge

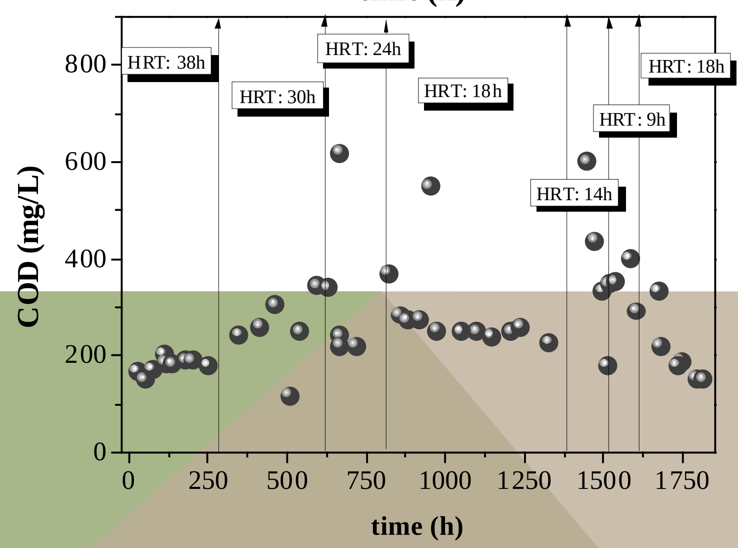
Ratio of total charge transferred to the anode to the maximum charge if all the substrate removal produced current

- ✓ Few hours after glucose addition, the voltage reached to 0.2 V → electrochemically active bacteria were contained in the inoculum
- ✓ The COD removal efficiency → 83%
- ✓ CE →10.8%
- ✓ Last cycle: 0.63 V and CE → 22.5 %

$$CE = \frac{M \int_0^t I * dt}{F * b * V * \Delta(COD)}$$

Experiments with glucose



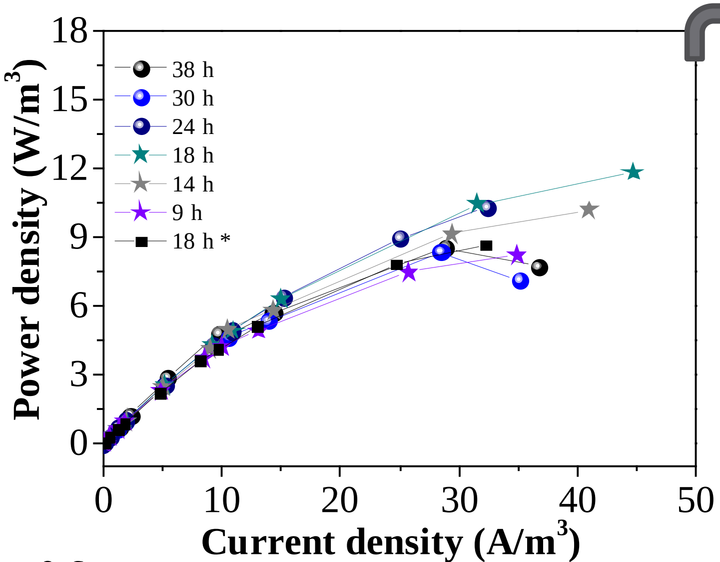


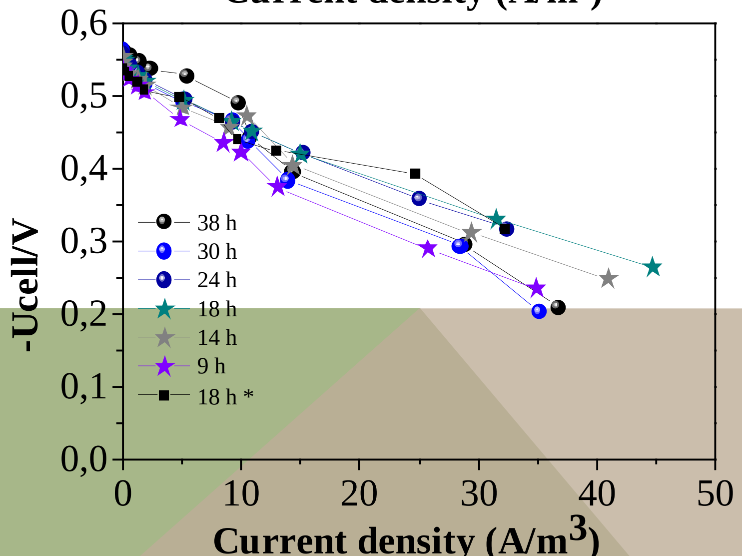
- ✓ Glucose (787 ± 39 mg COD/L)
- ✓ Continuous mode
- ✓ R=100 Ω
- ✓ HRTs: 38, 30,24,18,14,9,18 h

HRT (h)	COD removal efficiency (%)	CE (%)
38	76,0	19,1
30	67,5	16,3
24	71,1	12,1
18	68,7	12,4
14	52,6	11,7
9	55,7	7,6
18	77,6	10,9

- ✓ Lower HRTs→ lower COD removal efficiency
- ✓ Lower HRTs →lower CE (7.6 % at the HRT: 9 h)

Experiments with glucose





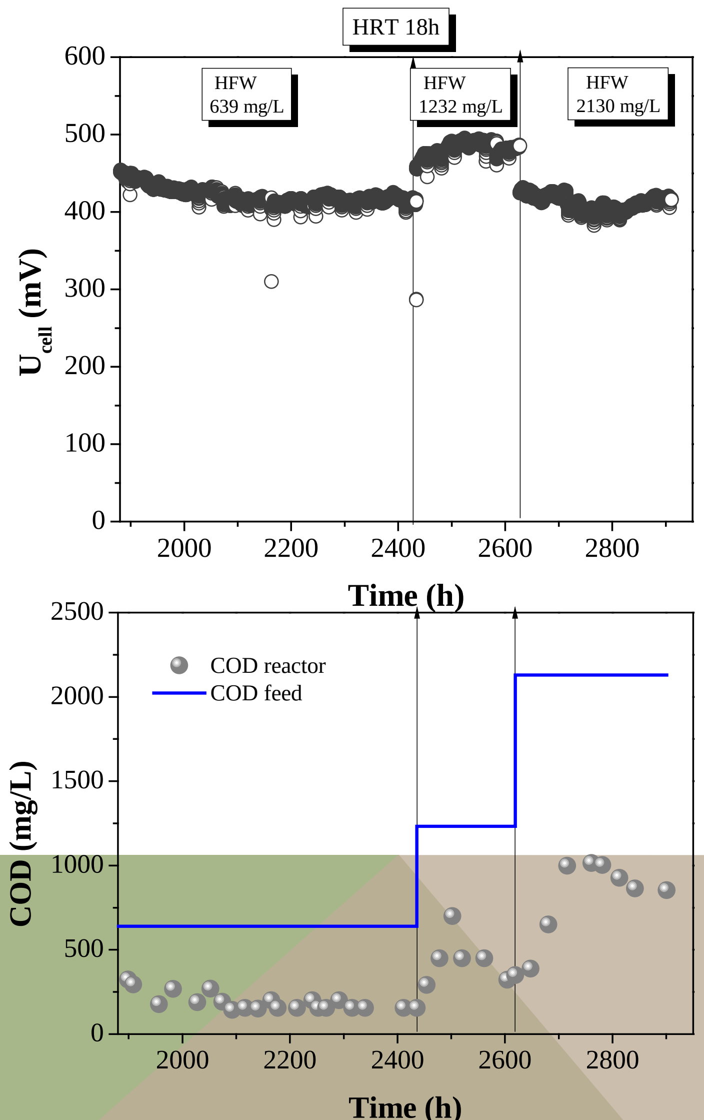
Data obtained by polarization curves (R=0.1 -1000 kΩ)

HRT (h)	CE (%)	P_{max} (W/ m³)	P_{max} (MJ/ kg COD_{in})
38	19,1	8,6	1.50
30	16,3	8,4	1.15
24	12,1	10,3	1.13
18	12,4	11,8	0.97
14	11,7	10,2	0.65
9	7,6	8,2	0.34
18	10,9	8,7	0.72

- ✓ Maximum power density 11.8 W /m³ at HRT 18h
- ✓ The internal resistance of the MFC is very low (20 Ω at the HRTs: 38 and 30 h and R<10 Ω for lower HRTs)
- ✓ Higher HRTs give higher overall power yields
- ✓ Returning to an HRT of 18h, the system did not totally recover

RESULTS
HFW as substrate

Experiments with HFW

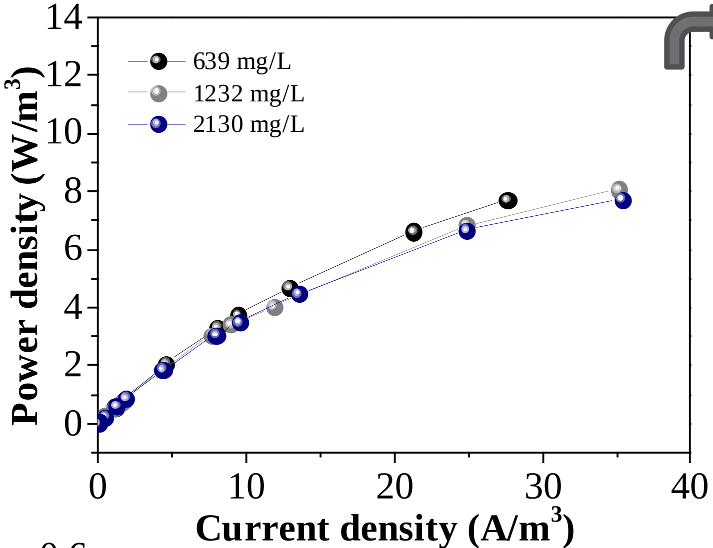


- ✓ Continuous mode
- ✓ R=100 Ω
- ✓ HRT: 18 h
- ✓ Different initial substrate concentrations

COD (mg/L)	COD removal efficiency (%)	CE (%)
639 ± 30	74.0	12.3
1232 ± 52	71.3	7.76
2130 ± 69	55.7	4.79

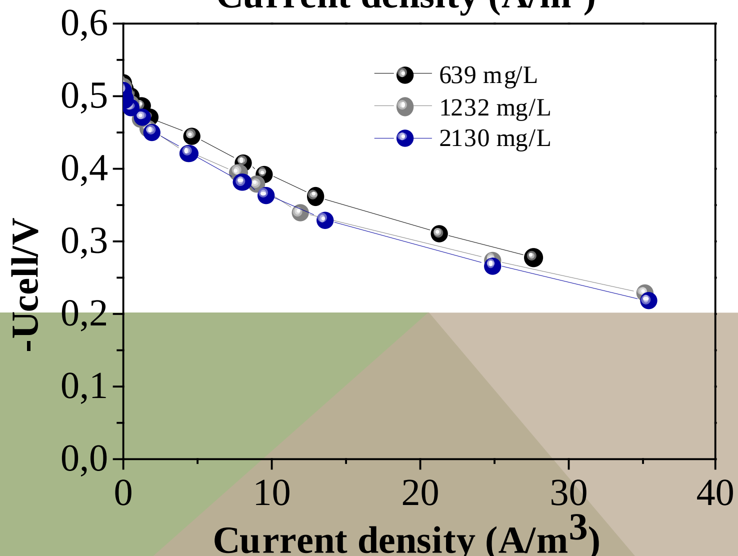
- ✓ Higher substrate concentrations → lower COD removal efficiency and lower CE
- ✓ At the higher COD concentration: the system started to be kinetically limited

Experiments with HFW



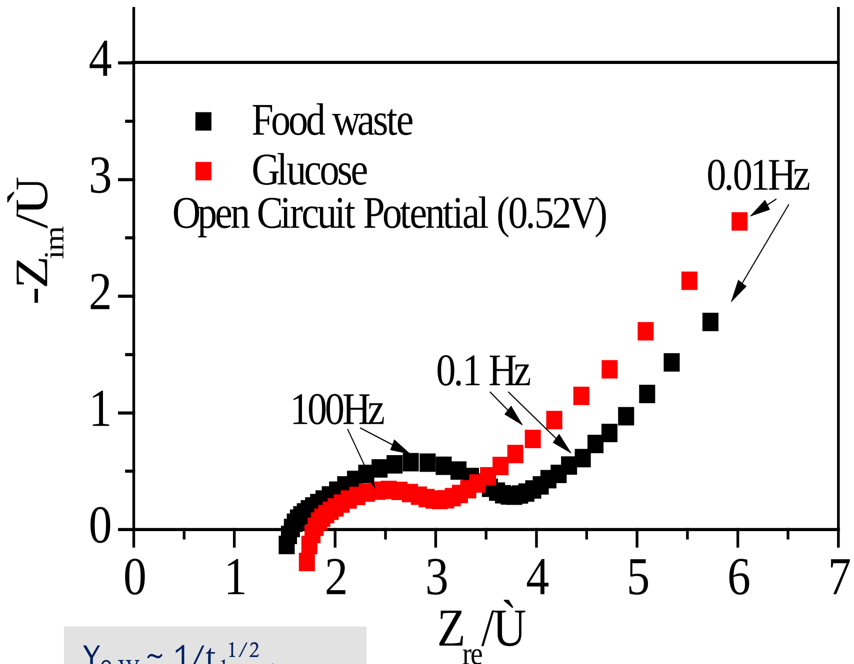
Data obtained by polarization curves (R=0.1 -1000 kΩ)

COD (mg/L)	CE (%)	P_{max} (W/ m^3)	Energy (MJ /kg COD)
639 ± 30	12.3	7.7	0.78
1232 ± 52	7.76	8.1	0.43
2130 ± 69	4.79	7.7	0.23



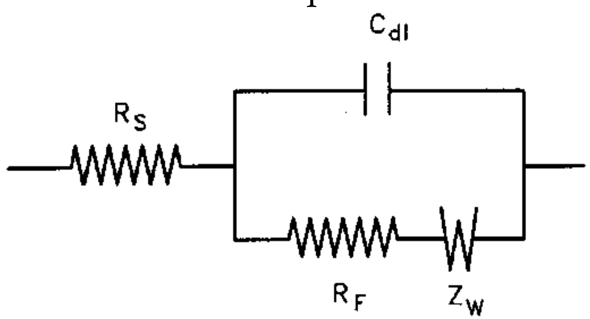
- ✓ Satisfactory energy yield and power density
- ✓ The substrate concentration did not seem to affect considerably P_{max}
- ✓ Lower concentration of COD led to higher yield of energy

Impedance characteristics of the MFC under open circuit conditions



Mass transfer limitations are evident in the Nyquist plot (Warburg impedance Z_w → almost straight line below ca. 10 Hz, inclined at 45° to the Z_{re} axis)

Impedance data were fitted to equivalent circuit below:



$Y_{0,W} \sim 1/t_d^{1/2}$,
t_d : relaxation time for diffusion

	Glucose	Food waste
$Y_{0,W}$ for W (Ω^{-1} $s^{0.5}$)	0.982 (± 1.6%)	1.575 (± 2.1%)
R_F (Ω)	1.613 (± 3.7%)	2.372 (± 1.4%)

Q: Constant phase element ($Z_Q = Y_{0,Q}^{-1}$ $(j\omega)^{-n}$)

W: Warburg element ($Z_W = Y_{0,W}^{-1}$ $(j\omega)^{-1/2}$)

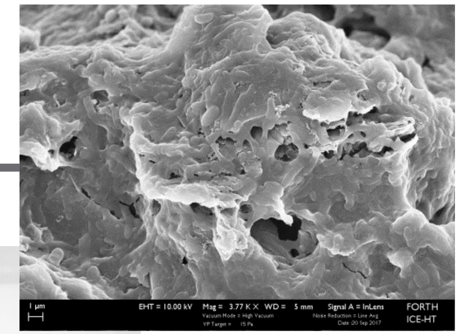
R_F: Charge transfer (faradaic) resistance

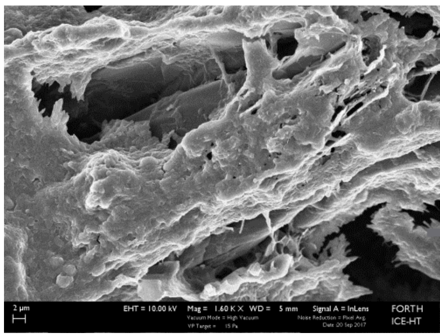
R_S: Ohmic resistance

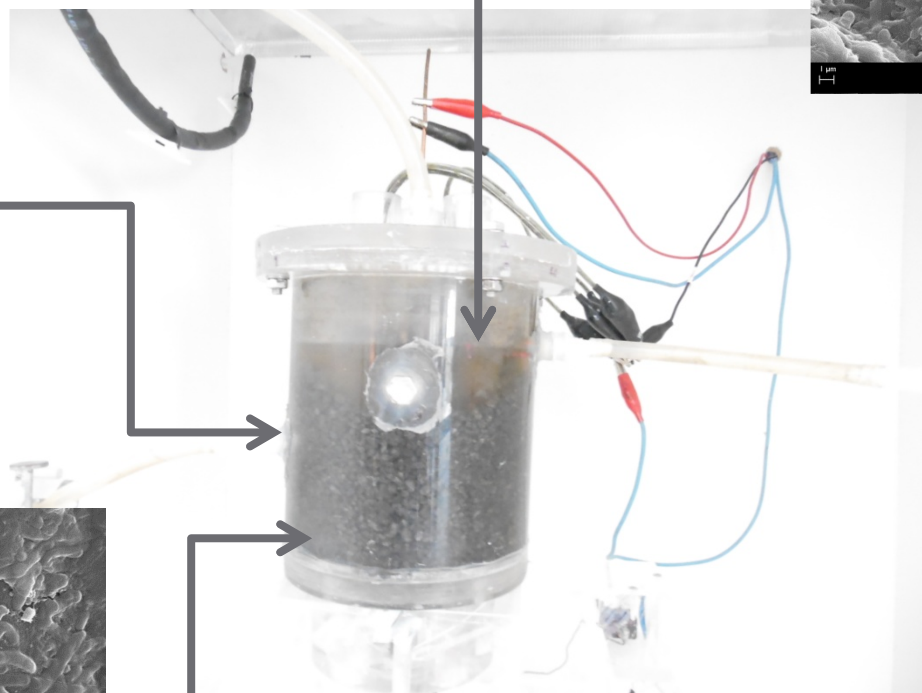
Mass transfer limitations less pronounced for HFW

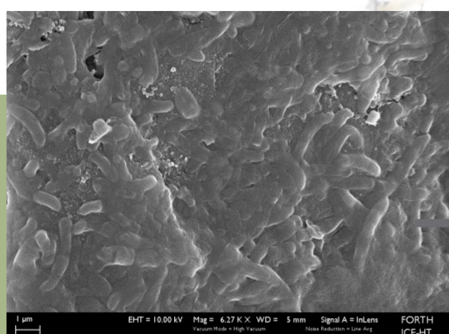
Experiments with HFW

SEM images at different heights



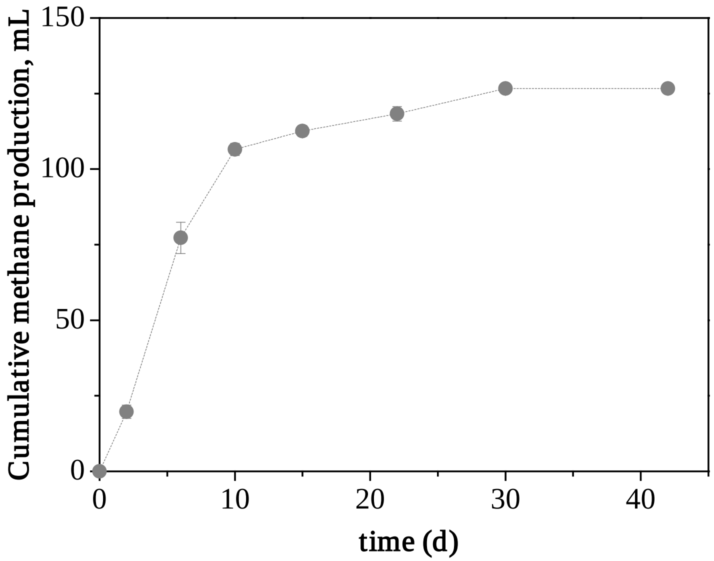






mass transfer limitations → intense biofilm formation all around the granules

Methane production from the solid fraction of extraction process



Methane yield (L / kg TS solid fraction)	Methane yield (L CH_4/ kg TS HFW)
434 ± 1	330 ± 1

- ✓ High BMP value of the solid fraction obtained after extraction process
- ✓ High biodegradability of HFW

Energy density (kJ/L)
Methane: 36.4

11979 kJ/kg
or
12 MJ /kg TS of HFW

Conclusions

- Valorisation of typical HFW was performed via its bioconversion a) to electricity through a MFC and b) methane through AD
- Optimization of the extraction process was based on the maximum concentration of soluble COD of the extract (→20 % wTS/v, 25 ^oC, 30 min)
- The MFC was initially operated using a synthetic nutrient solution based on glucose and the effect of the HRT (38, 30,24,18,14,9,18 h) was investigated.
  - Lower HRTs → lower COD removal efficiency and lower CE
  - At the HRT of 18 h: P_{max}=11.8 W/m^3
- Glucose was replaced by the HFW extract the effect of the organic loading rate was studied
  - Lower substrate concentrations→ higher COD removal efficiency and CE
  - At the higher COD concentration: the system started to be kinetically limited
  - Lower substrate concentrations → higher energy yield (0.78 MJ/kg TS HFW)

- The solid residue from the extraction process was used for methane production via BMP experiments
  - 330 ± 1 L CH4 /kg TS or 12 MJ /kg TS

- The combined valorization of HFW for the production of electricity through a MFC and CH_4 through AD is a promising approach.

Thank you for your attention !

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