Electrostimulated granular sludge bioreactors: from the lab to real-life ELSAR®

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Background and Introduction

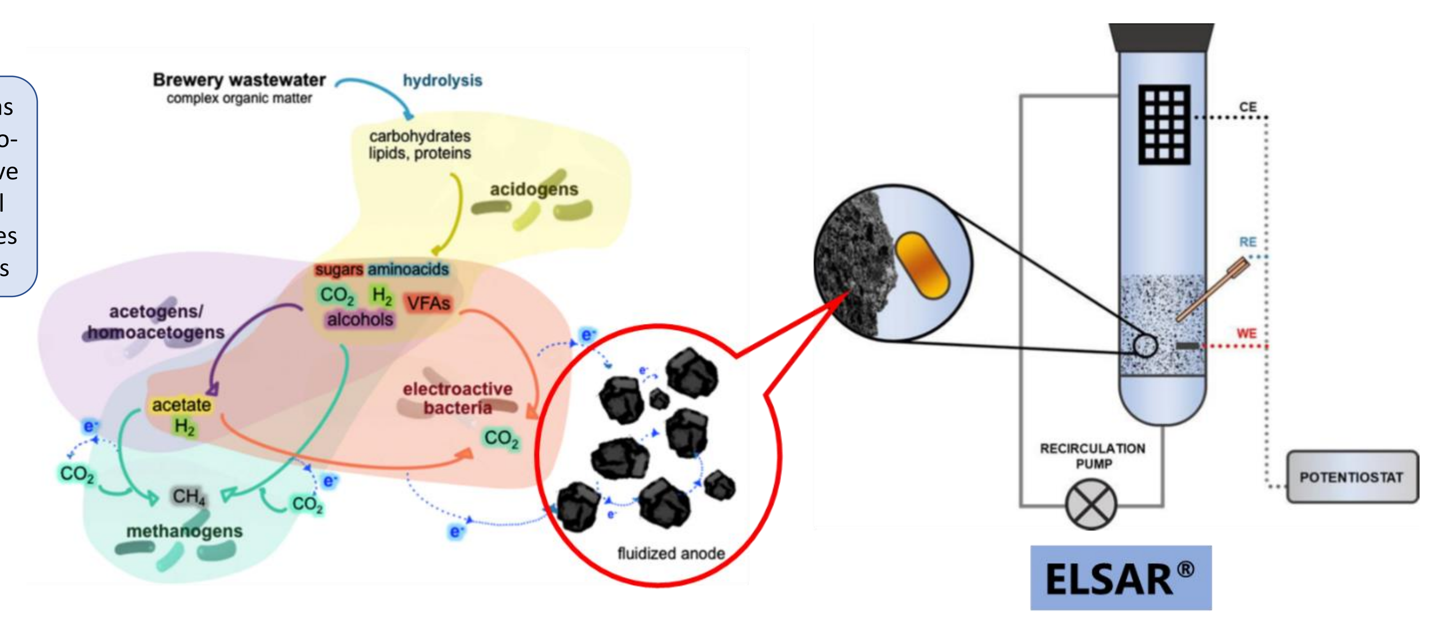
Coupling anaerobic digestion with electrochemistry have shown promising results and opens a wide spectrum of possibilities in the wastewater sector due, among others, to the extra methane production that takes place thanks to bioelectrochemical electron transfer pathways on electrodes and to its robustness [3].

The use of a microbial electrochemical fluidized bed reactor (pat. EP 2927196 A1) registered as Electro-Stimulated Anaerobic Reactor (ELSAR®) has been reported as a suitable solution where electron transfer by electroactive bacteria allows to stimulate the degradation of organic matter [4].

ELSAR® = fluidized reactor + bioelectrochemical system

- Electroactive bacteria grow in fluidized bed of AC
- Bacteria transfer electrons from the oxidation of the OM_{WW} to AC
- The capacitive granules are discharged at a current collector (poised at a higher potential than granules)
- Power is produced

AC acts as an electro-conductive material that stores electrons



Adapted from [2] and [4]

AC = Activated carbon. OM_{WW} = Organic Matter present in wastewater. WE = Working Electrode. RE = Reference Electrode. CE = Counter Electrode.

Objectives

- Evaluation and comparison (ELSAR® *vs.* conventional anaerobic fluidized bed reactor) in terms of performance, resilience, energetic efficiency and capacity.
- Comprehensive evaluation and optimization of the main bioelectrochemical elements of ELSAR®.
- Sketch out the strategy for a challenging scaling-up of ELSAR®.

Methods

Two kind of reactors were used to achieve the abovementioned objectives. Both were designed and assembled in methacrylate with a tubular geometry.

The design assure the fluidization of the sewage sludge and the electro-conductive anode material though the column.

The conditions for each test are described in the attached table.

Test [Reference]	Pre-pilot scale [1]	Lab-scale [2]
Reactor volume	5.4 L	1.2 L
Loading rate	6.0–7.1 kg COD/(m^3·d)	0.23 to 23.60 kg COD/(m^3·d)
HRT	9h	12 h
Configuration	Polarization by means of potentiostat of anode material at 0.6V (vs. Ag/AgCl reference electrodes)	
Inoculum	1:1 (v/v) Anaerobic granular sludge from brewery WWTP : activated sludge from chemical coagulated wastewater.	Anaerobic granular sludge (5 mL) from brewery WWTP.
Activated carbon	Aquasorb®, Germany, 20%v:v	Ø 0,6-1.0mm, Chemviron Carbon®, Belgium
Anode collector	Graphite plate, 4.5 cm × 4.5 cm	Graphite plate, 2.0 cm × 8.0 cm
Cathode collector	Stainless-steel (SS) sponge	SSmesh (2×8 cm) vs. SS sponge (4×15 cm); PAMEX®, Spain)
Tests	i) COD Overload: (1) 27.2 kg COD/(m^3·d); (2) 51.2 kg COD/(m^3·d) ii) Biocide used in food and beverage sector: didecyldi-mehtylammonium chloride (DDAC) iii) Starving period: no feed iv) Low temperature: sudden change to 25ºC Monitoring: see table	i) Activated carbon concentration (%v:v) 5%, 10%, 20%, 30% ii) SS mesh vs. SS sponge Monitoring of anode potential, cathode potential and cell potential, 3 times / day, for 7 days.

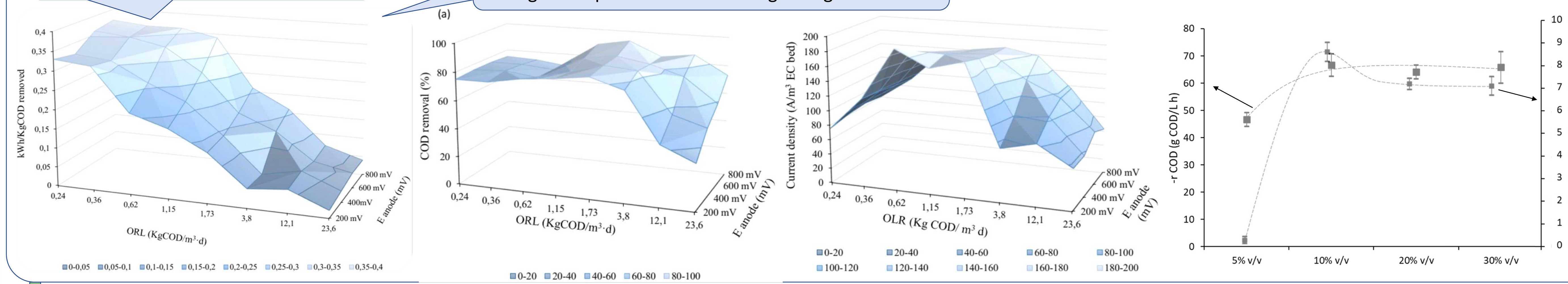
Resilience test	Operation time (d)	Monitored parameter
No resilience tests (Standard operation of AFBR and ME-FBR)	1–31 39–52	COD removal, biogas and hydrogen generation, power generation, nutrients removal
COD overloads	32–38 53–59	COD consumption rate, biogas and hydrogen generation
Biocide dosing	73–79	TN consumption rate
Starvation period	88–110	COD removal
Low temperature	306–340	COD removal

Results and Conclusions

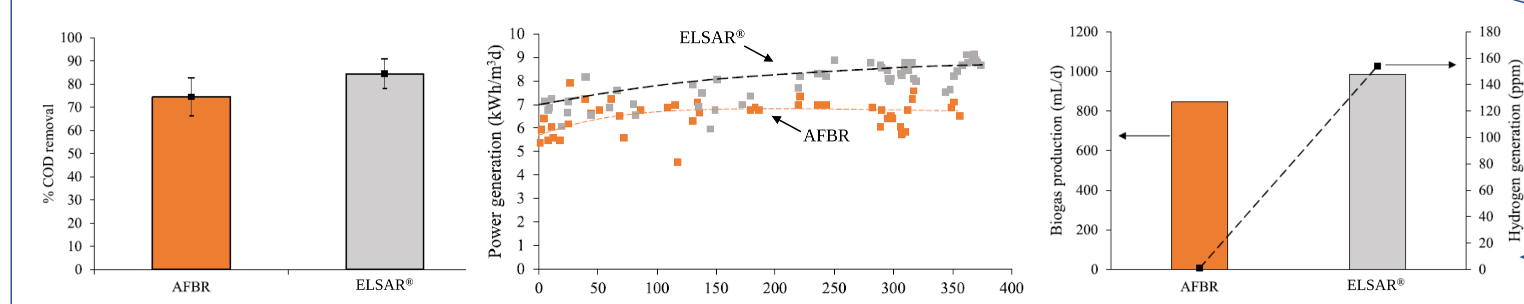
Energy consumption of ELSAR® in all cases was < 0.4 kWh/kg removed COD

Values up to 10-fold lower in comparison to typical energetic requirements of aerating biological reactors

Deep understanding of ELSAR® features [2]



[1] **ELSAR® outperforms anaerobic fluidized bed reactor (AFBR)**



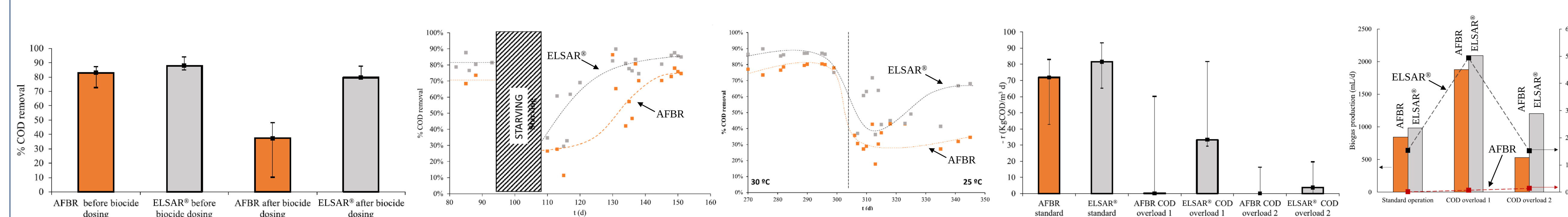
COD removal ***Energy generation*** ***Biogas production & H_2 concentration***

In concordance with was widely reported in several references in other anaerobic bioelectro-chemical systems (Park *et al.*, 2020).

Moreover, a surprising removal rate in both nutrients was observed, being up to 66% for total nitrogen and 75% for total phosphorous [2].

The increase in the generation of hydrogen increases the calorific power of the biogas produced, hence improving the energetic efficiency of the system.

ELSAR® exhibited to be more resilient and robust than anaerobic fluidized bed reactor (AFBR) under several stress conditions [1]



Biocide dosing ***Starvation*** ***Low temperature shock*** ***COD overload***

Promising results encouraged Aqualia to think in a pre-commercial proof of ELSAR® for industrial contexts

BEAD upscaling is challenging

Design guidelines

- Prioritize low A/V (electrode area : reactor volume) designs and affordable electrode materials (CF, SS) → low CAPEX
- Minimize distance between anodic and cathodic collector → minimum ohmic resistance
- Minimize fluidification velocity difference between sludge and AC → easy coexisting of anode + biomass

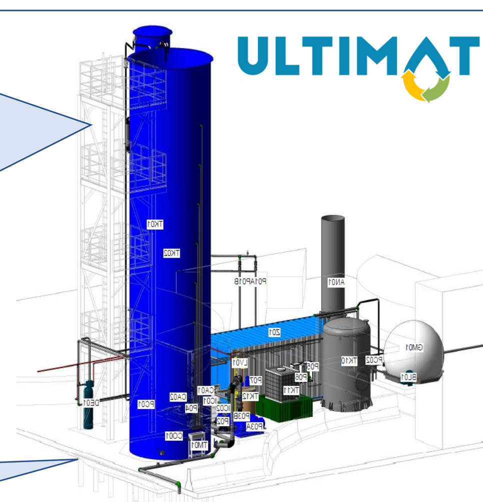
Previous (before building) verification & testing

- Electrical tests of materials
- Verify expansion by means of CFD study and lab-scale
- Lab-scale verification of definitive electrode configuration

Foreseen pre-commercial ELSAR®

- Reactor features:
  - Flow 20 m^3/h
  - Loading Rate 2000 kg COD/d
  - Mesophilic range (30 - 37ºC)
- Expected results:
  - 90% COD removal
  - 31 Nm^3 biogas/h
  - Start-up in 2023

On behalf of the EU project H2020 ULTIMATE (www.ultimatewater.eu)



BEAD = bioelectrochemical anaerobic digestion. OLR = Organic Loading Rate. CFD = Computational Fluid Dynamics; AC = activated carbon; CF = Carbon Fiber. SS = Stainless steel

References

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Acknowledgements

The authors would like to thank the European Union's Horizon 2020 research and innovation programme, which provided the needed funding under the Grant Agreement No 869318.