# ULTIMATE

**WATER SMART INDUSTRIAL SYMBIOSIS**

# Factsheet:

# Electrostimulated anaerobic reactor (ELSAR™)

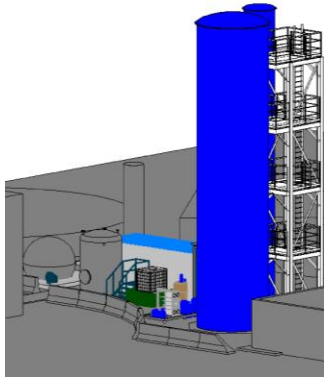AUTHORS: A. Kleyböcker, A. Gimenez Lorang

DATE: 25/11/2021

VERSION: V3

# Electrostimulated anaerobic reactor (ELSAR™)



**Unique selling points:**

- ✓ Energy recovery in the form of biogas
- ✓ Higher organic loading rates compared to anaerobic digestion
- ✓ Increased process stability
- ✓ Short stabilisation periods after shock loads
- ✓ Higher calorific value of the biogas due to higher $H_2$ content

### Description of the technology

The electrostimulated anaerobic reactor (ELSAR™) combines **anaerobic digestion** with bioelectrical processes. It can be applied as anaerobic pretreatment of raw wastewater with high COD loads or as sludge treatment. Until now the majority of bioelectrochemical processes have only been operated in lower scale configurations (**Park et al. 2020a**). In Ultimate, one of the first industrial scale system treating 450 m³/d of wastewater is demonstrated (**CS Lleida**). The reactor is basically a combination of an upflow anaerobic sludge blanket reactor (UASB) with integrated electrodes (Fig. 1).

Here, organic matter is converted to biogas by fermentative and methanogenic microorganisms. Due to the integrated bioelectrical system, electroactive microorganisms oxidize organic matter and release electrons to the anode as well as hydrogen ions and $CO_2$ (**Torres et al. 2007**). Those substrates are used by other microorganisms together with the electrons released by the cathode to produce hydrogen gas and subsequently methane.

In detail, three mechanisms can play a role: (1) direct bioelectrochemical methanation, (2) $H_2$-mediated methanation also known as hydrogenotrophic methanogenesis and (3) carbon compounds-mediated methanation consisting of autotrophic acetogenesis combined with acetoclastic methanogenesis (**Park et al. 2020a**). The different pathways enable a high flexibility and thus, allow for maintaining a stable biogas formation process. Hence, the bioelectrical process increases the methane production rate compared to typical anaerobic systems (**Zhang et al. 2018, Park et al. 2020b**) and shortens stabilisation periods after shock loads (**De Vrieze et al. 2018, Park et al. 2020b**).

### Flow scheme of the technology

The electrostimulated anaerobic reactor is an upflow anaerobic sludge blanket reactor with integrated electrodes (Fig. 1). The electroconductive anode consists of the fluidized bed made of activated carbon particles. This anode transfers the electrons via collision to a static graphite electrode with a polarized structure. The granular activated carbon is be added only once, during the start-up. However, some extra GAC injections may be necessary to compensate losses (purge, treated water). Because of their higher density than that of the

biomass granules, GAC will be slightly fluidized (expected < 40%) and therefore it will be located in the lowest zone of the bioreactor.
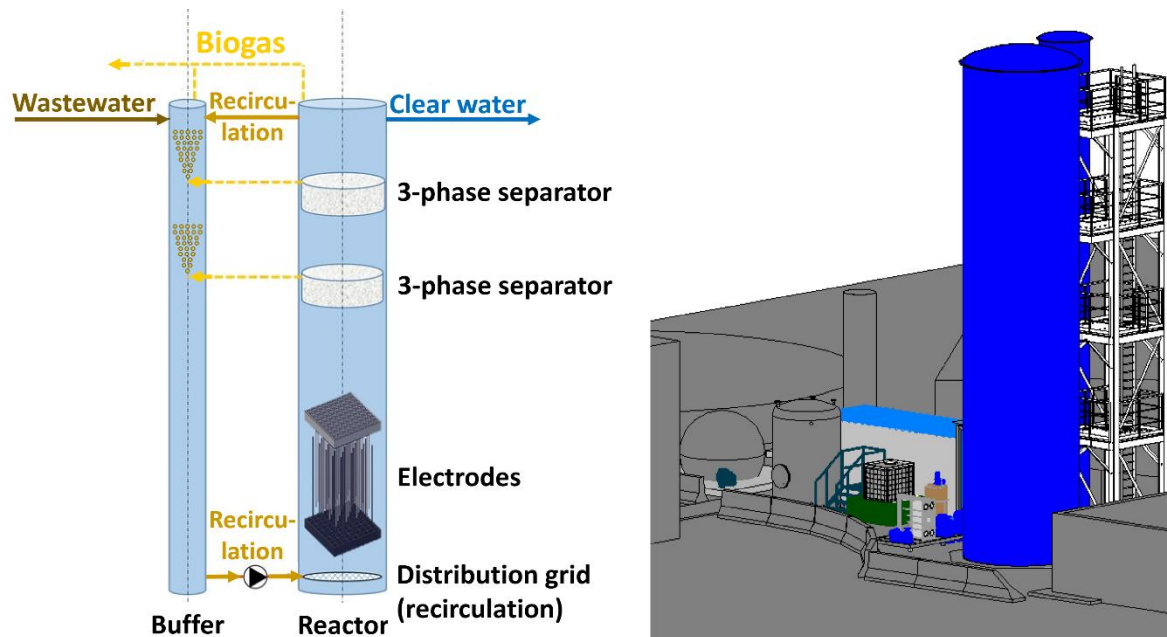


**Fig. 1 Electrostimulated anaerobic reactor (ELSAR): UASB reactor with integrated electrodes**

The wastewater is pumped in the reactor at the bottom and flows to the top in a vertical cylindrical reactor. The 3-phase separator separates the gas, liquids and solids (granular activated carbon and granular sludge). The granules settle down to the bottom. The liquid stream and the biogas bubbles ensure good mixing conditions.

In the buffer tank (same height, less diameter than the reactor), the pH and the temperature of the inlet wastewater are adjusted by means of chemical addition (NaOH or HCl) and heating (Ultimate case study: 30-37°C), respectively. The biogas is collected in every separator and recirculated to add alkalinity to the inlet wastewater. On the top of the reactor, the clear water is collected.

**Pictures of the technology and product**
*Will be added later, when available*

**Synergetic effects and motivation for the implementation of the technology**
    ✓ **Higher methane production rates compared to anaerobic digestion**

The bioelectrochemical anaerobic digestion accelerates the hydrogen production due to the release of hydrogen ions from organic matter during electrolysis (**Park et al. 2020b**). The higher availability of hydrogen together with $CO_2$ allows hydrogenotrophic methanogens to produce more methane due to higher process efficiencies and due to faster production rates (**Park et al. 2020a**).

Furthermore, **An et al. 2020** showed, that electroactive bacteria rapidly enriched on the surface of an electrode as well as in the bulk solution and adapted themselves to the conditions in the reactor. Due to their contribution to methane production via the direct

interspecies electron transfer pathways on the electrode and in the bulk solution, the methane production rate increased significantly (**An et al. 2020**).

✓ **Shorter stabilisation periods compared to anaerobic digestion**

**Park et al. 2019** and **Asensio et al. (2021)** showed that bioelectrochemical anaerobic digestion overcomes the imbalance during shock loads or high organic loading rates between 10 kg COD/(m³*d) and 24 kg COD/(m³*d), because electroactive microorganisms oxidize organic matter and release electrons to the anode as well as hydrogen ions ($H^+$) and $CO_2$. In parallel, hydrogenotrophic methanogens convert rapidly the $H^+$ using the electrons released from the cathode to $H_2$. Hence, the pH can be regulated and an accumulation of volatile fatty acids can be decreased due to the rapid conversion of organic acids to $H_2$ and $CO_2$.

**Requirements of the technology and operating conditions**

As for an UASB reactor, the hydraulic retention time is decoupled from the sludge blanket residence time (Tab. 1). The reactor temperature is usually at 37 °C or 55 °C for mesophilic or thermophilic organisms, respectively. The pH of the inflow must be neutral or slightly above, because the methanogens are very sensitive to an acidic pH. The organic loading rate is usually operated between 10 and 24 kg COD/(m³*d) and the sludge content should vary between 3 and 4%. For the mixing conditions, the liquid upflow velocity plays a crucial role and is depending on the reactor geometry between 1 and 6 m/h.

For the electrodes, usually, the applied voltages range between 0.2 and 1.5 V depending on the type of substrate. The current densities also depend on the type of substrate and range between 0.45 and 9 A/(m² electrode surface area).

**Tab. 1 Typical ranges for operating parameters**

| Parameter | Units | Min | Max | Reference |
|---|---|---|---|---|
| **Organic loading rate** | kg COD/(m³*d) | 10 | 24 | **Park et al. 2020a; Metcalf et al. 2013; Asensio et al. 2021b** |
| **Sludge content** | % | 3 | 4 | **Metcalf et al. 2013** |
| **pH** | - | 7 | 8.5 | **Chen et al. 2008** |
| **Temperature** | °C | 35 | 55 | **Deublein et al. 2008** |
| **Hydraulic retention time (UASB)** | h | 4 | 10 | **Deublein et al. 2008, Metcalf et al. 2013** |
| **Sludge blanket residence time** | d | >30 | | **Metcalf et al. 2013** |
| **Liquid stream velocity** | m/h | 1 | 6 | **Metcalf et al. 2013** |
| **Applied voltages** | V | 0.2 | 1.5 | **Park et al. 2020a, Asensio et al. 2021** |
| **Current densities** | A/m² | 0.45 | 9.0 | **An et al. 2020, Asensio et al. 2021, Torres et al. 2007** |

**Key performance indicators**

Depending on the types of substrates, the methane yields vary as shown in Tab. 2. The COD removal rates of around 86% of a bioelectrochemical anaerobic reactor are higher than those of non-electrochemical systems such as aerobic membrane bioreactors, sequencing batch reactors and anaerobic UASB reactors ranging between 70%-80% (**Asensio et al. 2021**).

**Tab. 2 Average methane yields and COD removal efficiencies for different types of substrate in a bioelectrochemical anaerobic reactor; oDM organic dry matter**

| Parameter | Unit | Methane yield | References |
|---|---|---|---|
| Food waste | m³/(kg oDM) | 0.53 | Park et al. 2018 |
| Distillery wastewater | m³/(kg oDM) | 0.48 | Feng et al. 2017 |
| Brewery wastewater | m³/(kg oDM) | 0.22 | Sangeetha et al. 2016 |
| | Unit | COD removal | |
| Brewery wastewater | % | 85-87 | Sangeetha et al. 2016, Asensio et al. 2021 |

For waste activated sludge as substrate, **Cai et al. 2016** and **Bo et al. 2014** observed in their laboratory experiments a two-fold higher methane yield in the bioelectrochemical system than for their conventional anaerobic digester control reactors.

**Links to related topics and similar reference projects**

| Process/technologies | Reference |
|---|---|
| Enhanced biogas production due to thermal hydrolysis process (THP) | Case study "Braunschweig" (NextGen) |
| Anaerobic membrane reactor (AnMBR) | Case study "Spernal" (NextGen) |
| Anaerobic high rate reactor (AAT) | Case study "Shafdan" & Case study "Karmiel" (Ultimate) |
| Anaerobic digestion | Factsheet in TEB |

**References**

An, Z., Feng, Q., Zhao, R., Wang, X. (2020). Bioelectrochemical methane production from food waste in anaerobic digestion using a carbon-modified copper foam electrode. Process, 8, 416, https://doi.org/10.3390/pr8040416

Asensio, Y., Llorente, M., Tejedor-Sanz, S., Fernández-Labrador, P., Manchon, C., Ortiz, J.M., Ciriza, J.F., Monsalvo, V., Rogalla, F., Esteve-Núñez, A. (2021). Microbial electrochemical fluidized bed reactor (ME-FBR): An energy-efficient advanced solution for treating real brewery wastewater with different initial organic loading rates. Journal of Environmental Chemical Engineering, 9, 6, https://doi.org/10.1016/j.jece.2021.106619

Bo, T., Zhu, X., Zhang, L., Tao, Y., He, X., Li, D., Yan, Z. (2014). A new upgraded biogas production process: Coupling microbial electrolysis cell and anaerobic digestion in single-chamber, barrel-shape stainless steel reactor. Electrochemistry Communications, 45, 67-70. https://doi.org/10.1016/j.elecom.2014.05.026.

Cai, W., Liu, W., Yang, C., Wang, L., Liang, B., Thangavel, S. Zechong Guo, Z., Wang A. (2016). Biocathodic methanogenic community in an integrated anaerobic digestion and microbial electrolysis system for enhancement of methane pioduction from waste sludge. ACS Sustainable Chemistry & Engineering, 4, 9, 4913-4921, https://doi.org/10.1021/acssuschemeng.6b01221

Chen, Y., Cheng, J., Creamer, K. (2008). Inhibition of anaerobic digestion process: A review. Bioresource Technology, 99, 4044-4604. https://doi.org/10.1016/j.biortech.2007.01.057

De Vrieze, J., Arends, J., Verbeeck, K., Gildemyn, S., Rabaey, K. (2018). Interfacing anaerobic digestion with bioelectrical systems: potentials and challenges. Water Research, 146, 244-255. https://doi.org/10.1016/j.watres.2018.08.045

Deublein, D., Steinhauser, A. (2008). Biogas from waste and renewable resources, Wiley-VCH Verlag GmbH & Co.Kg, Weinheim, 443 p. ISBN: 978-3-527-32798-0

Feng, Q., Song, Y., Yoo, K., Kuppanan, N., Subudhi, S., Lal, B. (2017). Bioelectrochemical enhancement of direct interspecies electron transfer in upflow anaerobic reactor with effluent recirculation for acidic distillery wastewater. Bioresource Technology, 241, 171-180. https://doi.org/10.1016/j.biortech.2017.05.073

Metcalf & Eddy, Inc., Tchobanoglous, G., Stensel, H., Tsuchihashi, R. Burton, F. (2013). Wastewater Engineering: Treatment and Resource Recovery, Fifth Edition, McGraw-Hill Education, New York, 2018 p. ISBN 978-0-07-340118-8

Liu, W., Cai, W., Guo, Z., Wang, L., Yang, C, Varrone, C., Wang, A. (2016). Microbial electrolysis contribution to anaerobic digestion of waste activated sludge, leading to accelerated methane production. Renewable Energy, 91, 334-339. https://doi.org/10.1016/j.renene.2016.01.082.

Park, J., Lee, B., Tian, D., Jun, H. (2018). Bioelectrochemical enhancement of methane production from highly concentrated food waste in a combined anaerobic digester and microbial electrolysis cell. Bioresource Technolology, 247, 226–233. https://doi.org/10.1016/j.biortech.2017.09.021

Park, J., Lee, B., Kwon, H., Park, H., Jun, H. (2019). Effects of a novel auxiliary bio-electrochemical reactor on methane production from highly concentrated food waste in an anaerobic digestion reactor. Chemosphere, 220, 403-411. https://doi.org/10.1016/j.chemosphere.2018.12.169

Park, J., Jiang, D., Lee, B., Jun, H. (2020a). Towards the practical application of bioelectrochemical anaerobic digestion (BEAD): Insights into electrode materials, reactor configurations, and process designs. Water Research 184, 116214, https://doi.org/10.1016/j.watres.2020.116214

Park, J., Heo, T., Kwon, H., Shi, W., Jun, H., (2020b). Effects of voltage supply on the methane production rates and pathways in an anaerobic digestion reactor using different electron donors. International Journal of Hydrogen Energy 45, 16, 9459–9468. https://doi.org/10.1016/j.ijhydene.2020.01.237

Sangeetha, T., Guo, Z., Liu, W., Cui, M., Yang, C., Wang, L., Wang, A. (2016). Cathode material as an influencing factor on beer wastewater treatment and methane production in a novel integrated upflow microbial electrolysis cell (Upflow-MEC). International Journal of Hydrogen Energy, 41, 4, 2189-2196. https://doi.org/10.1016/j.ijhydene.2015.11.111

Torres, C., Marcus, A., Rittmann, B. (2007). Kinetics of consumption of fermentation products by anode-respiring bacteria. Applied Microbiology and Biotechnology 77, 3, 689–697. https://doi.org/10.1007/s00253-007-1198-z

Zhang, S., Chang, J., Liu, W., Pan, Y., Cui, K., Chen, X., Liang, P., Zhang, Q., Qiu, Y., Huang, X. (2018). A novel augmentation strategy to accelerate methanogenesis via adding *Geobacter sulfurreducens* PCA in anaerobic digestion system. Science of the Total Environment, 642, 322-326. https://doi.org/10.1016/j.scitotenv.2018.06.043

**Outlook**

**Case study specific information will be provided, when the results of the other work packages are available:**

- **Water smart industrial symbiosis**
- **Operational challenges and lessons learned from the case study**
- **Outcome of the assessments**
- **Legal and regulatory information concerning the whole value chain concerning the technology**
- **Business opportunities**