

From Waste to Energy in the Fish Processing Industry: integration of pilot-scale Bioelectrochemically improved Anaerobic Digestion

Simone Colantoni ¹, Daniele Molognoni ¹, Miguel Marin ², Freddy Liendo ², Mohammad Mansouri ^{3,4}, Steinar Aamodt ⁵, Eduard Borràs ¹

¹Leitat Technological Center, C/ de la Innovació 2, 08225 Terrassa, Barcelona, Spain

²Hysytech S.r.l., Via I Maggio 5, Orbassano, TO, 10043, Italy

³NORCE Norwegian Research Centre, 4021 Stavanger, Norway

⁴Department of Energy and Petroleum Engineering, University of Stavanger, 4036 Stavanger, Norway

⁵Prima Protein AS, Hovlandsveien 64, 4373 Egersund, Norway

Keywords: biomethane, anaerobic digestion, bioelectrochemical systems, energy recovery

Corresponding author E-mail: dmolognoni@leitat.org

Abstract for oral presentation

In the fish processing industry, up to 50% of the starting raw material gets discarded in the form of waste [1]. However, these wastes are rich in biodegradable components and could represent a promising substrate for energy recovery via biogas production in anaerobic digestion (AD) [1]. One strategy that received attention for improving bioenergy recovery from the AD process is its integration with bioelectrochemical systems (BES) [2]. BES are a novel technology composed of an electrochemical cell where one or two (bio)electrodes are coated with a biological catalyst composed of electroactive microorganisms, capable of performing extracellular electron transfer with the solid electrodes. The integration of BES in AD (AD-BES) can offer several synergetic advantages, such as increased stability towards overloads and fluctuations, and increased methane production [2,3]. However, AD-BES technology currently operates at a Technology Readiness Levels (TRL) of 3-4, with most studies conducted at a laboratory scale. Few studies have explored pilot-scale systems (TRL 7), and no research has yet reported the integration of AD-BES into a real industrial environment.

This study evaluates the performance of a pilot-scale (1 m³) fully automated AD-BES, integrated into a fish processing factory, where it treated the industrial wastewater from fishery operations, while producing biogas. The AD-BES system was connected downstream to supply the produced biogas to a combined heat and power (CHP) unit. A picture of the pilot setup is reported in Figure 1. This is the first reported instance of an AD-BES unit fully integrated within an operational industrial setting. The unit was directly connected to the factory's processes, with automated feeding events triggered by production activity. Feeding events and the availability of hot water for the system thermostatic control depended on the factory's production schedule, which in turn depended on the availability of fish in the market — a stochastic factor. This study investigates the system's resilience to fluctuating organic loading rates and internal temperature (a result of the factory's irregular production), and evaluates their effects on key performance indicators, including biogas production, methane content and pH stability.

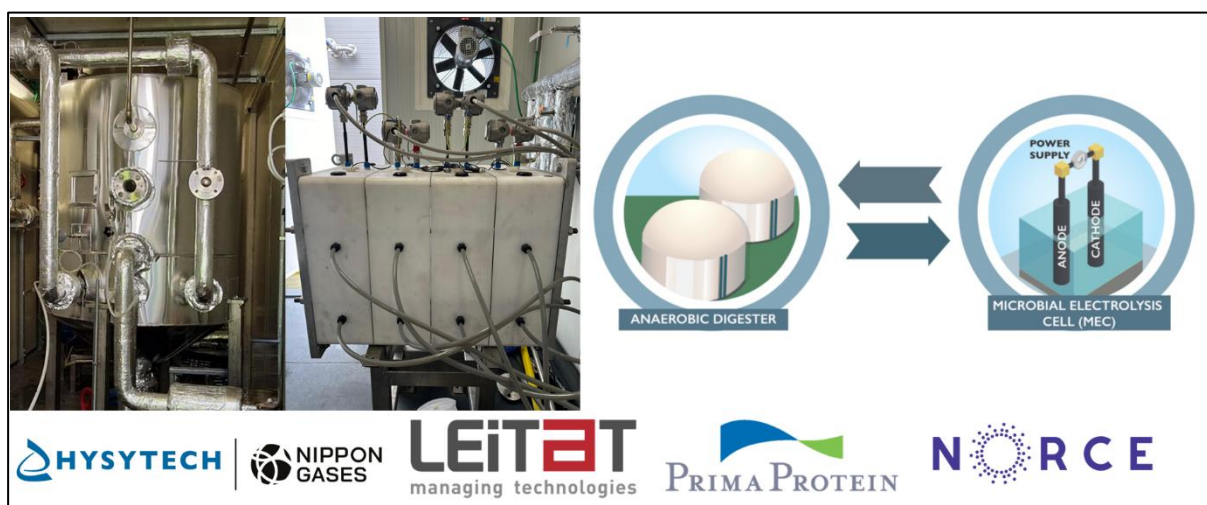


Figure 1. Photographic pictures of the pilot AD (left picture) and the BES module (middle picture). Schematic representation of the AD-BES process (right picture)

Biogas production was closely correlated with feeding events and temperature of the AD-BES (Figure 2-a). The results highlight the unit's operational inertia, allowing to maintain its performance under stochastic conditions. Although the AD-BES was designed for a hydraulic retention time (HRT) of 10 days, intermittent and unpredictable feeding, combined with the absence of a homogenization tank, resulted in a variable HRT. During normal operation (after the first 4 weeks of inoculation), HRT varied between 13 ± 7 days (Figure 2-b), corresponding with an average organic loading rate (OLR) of $0.7 \pm 0.3 \text{ kg}_{\text{COD}} \text{ m}^{-3} \text{ day}^{-1}$. The system achieved a weekly average biogas production rate of $0.2 \pm 0.1 \text{ m}^3 \text{ m}^{-3} \text{ day}^{-1}$ with peaks up to $0.5 \text{ m}^3 \text{ m}^{-3} \text{ day}^{-1}$, with a methane content exceeding 70%.

The BES module consisted of 4 hydraulically independent cells, electrically connected in series. The module was integrated in the recirculation loop of the main AD reactor. It demonstrated a stable electrical response of 0.1 A m^{-2} at a stack voltage of 1.2 V , with individual cell voltages averaging around 0.3 V . To enhance voltage stability, a cell-balancing system based on diodes was implemented to equalize the voltage of individual cells, under high-voltage operation. Comprehensive analyses of the liquid phase and microbial communities will provide further insight into microbial composition, resilience, and the effects of stochastic operating conditions.

The findings reported in this study are crucial for advancing the understanding and up-scale of the AD-BES process, with a view toward continuous industrial applications.

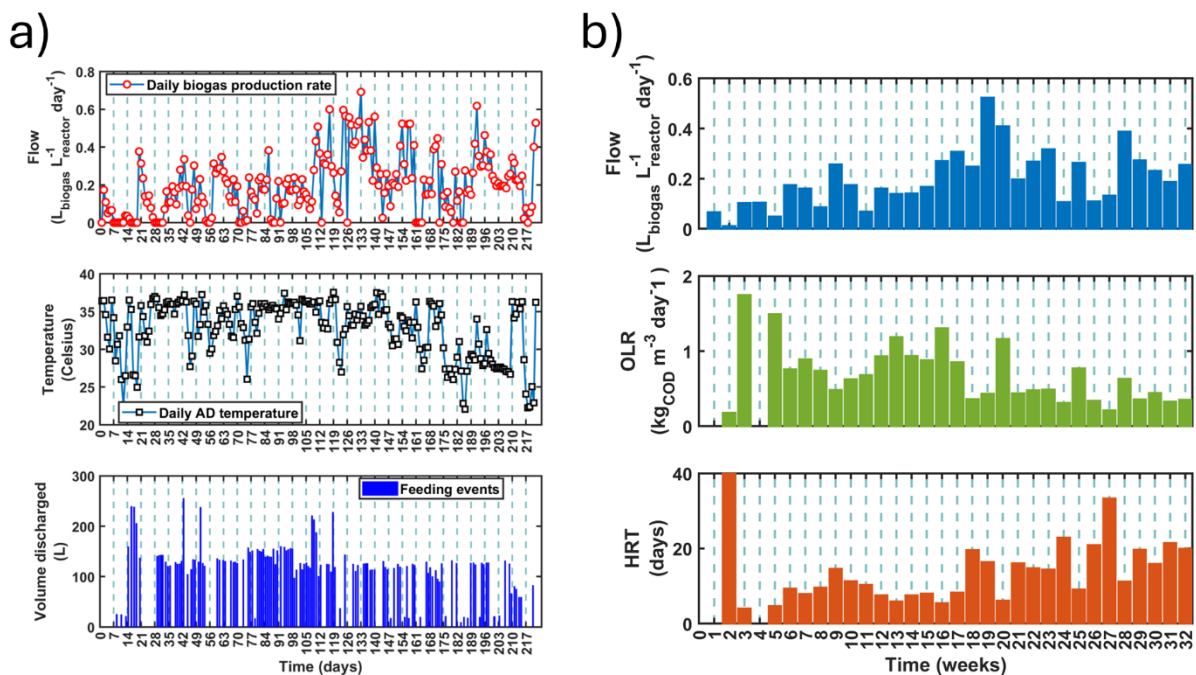


Figure 2-a. Daily trends over 210 days, including biogas production rate (Top panel), digester temperature (Middle panel) and feeding events with volume discharged (Bottom panel) **Figure 2-b.** Temporal variation of key operational parameters over 32 weeks during anaerobic digestion of fishery industrial wastewater. Biogas flow rate (Top panel), organic loading rate (Middle panel) and hydraulic retention time (Bottom panel).

Acknowledgement

The authors would like to acknowledge the European Union's Horizon 2020 research and innovation programme for providing financial support to the "ROBINSON" project (under grant agreement No. 957752). It should be noted that this paper reflects only the authors' views, and the Research Executive Agency, and the European Commission are not liable for any use that may be made of the information contained therein.

Bibliography

- [1] M. Eiroa, J.C. Costa, M.M. Alves, C. Kennes, M.C. Veiga, Evaluation of the biomethane potential of solid fish waste, *Waste Management* 32 (2012) 1347–1352. <https://doi.org/10.1016/j.wasman.2012.03.020>.
- [2] S. Colantoni, D. Molognoni, P. Sánchez-Cueto, C. De Soto, P. Bosch-Jimenez, R. Ghemis, E. Borràs, Bioelectrochemically-improved anaerobic digestion of fishery processing industrial wastewater, *Journal of Water Process Engineering* 65 (2024) 105848. <https://doi.org/10.1016/j.jwpe.2024.105848>.
- [3] D. Molognoni, M. Garcia, P. Sánchez-Cueto, P. Bosch-Jimenez, E. Borràs, S. Lladó, R. Ghemis, G. Karakachian, Q. Aemig, G. Bouteau, Electrochemical optimization of bioelectrochemically improved anaerobic digestion for agricultural digestates' valorisation to biomethane, *Journal of Environmental Management* 373 (2025) 123898. <https://doi.org/10.1016/j.jenvman.2024.123898>.