A Microbial Electrolysis Cell-assisted Anaerobic Digestion process for enhanced treatment of industrial potato processing wastewater

FRAGKOS O.[1], KANELLOS G.[1], KOTSIKAS E.[1], POURNARA E.[1], VLYSIDIS A.[1], TREMOULI A.[1,*], LYBERATOS G.[1,2]

[1] School of Chemical Engineering, National Technical University of Athens, Iroon Polytechneiou 9, Zografou, 15780, Athens, Greece.
[2] Institute of Chemical Engineering Sciences (ICE-HT), Stadiou Str., Platani, 26504, Patras, Greece.

*corresponding author: TREMOULI A.
e-mail: atremouli@chemeng.ntua.gr

Abstract: This study deals with the treatment of an industrial potato processing wastewater, using a Microbial Electrolysis Cell-assisted Anaerobic Digestion (MEC-AD) system. For this purpose, two identical reactors were constructed, a control (AD) and a MEC-AD reactor. The MEC-AD reactor consisted of three anodic and three cathodic carbon felt electrodes. Both reactors operated for 160 d at a constant Hydraulic Retention Time of 15 d, whereas the effect of the applied voltage was evaluated on organic load degradation and biomethane production. The results showed that the MEC-AD reactor achieved increased particulate organic content degradation by 0.02 g_{COD}/(L d), and the increased hydrolysis rate of organic content led to a tenfold increase in the biogas production of the MEC-AD (0.2 L/d relative to 0.02 L/d for the AD). Furthermore, the MEC-AD demonstrated enhanced biogas quality (average CH_4 content being over twice that of the AD), as well as mitigation of hydrogen sulfide producing bacteria which are antagonistic to methanogens. The results showed that the MEC-AD reactor outperformed the AD, achieving enhanced waste treatment and higher CH_4 yield.
Keywords: Bio-electrochemical systems; Carbon electrodes; Electromethanosynthesis; MEC-AD

1. Introduction

Industrial potato processing wastewater (IPPW) is a major byproduct of potato processing industries, since during processing of 1 ton of potatoes, 7 m^3 of wastewater is produced (Kot et al., 2020). Therefore, the effective management of these substantial volumes are imperative to mitigate environmental impact and achieve resource recovery. Previous studies have investigated various technologies for the treatment of IPPW, including acidic-thermal coagulation (Kot et al., 2020), integrated approaches combining coagulation and filtration (Bouchareb et al., 2021) and Microbial Fuel Cells (Durruty et al., 2012). Among these, Anaerobic Digestion (AD) has emerged as a promising and widely explored strategy for IPPW treatment and has been studied under co-digestion schemes with multiple substrates (Monou et al., 2008), as well as in high-rate bioreactors (Zoutberg and Eker, 1999). However, the AD is limited by the slow hydrolysis rate of particulates and the suboptimal CH_4 content in the produced biogas. An upcoming technology to tackle the AD limitations is the Microbial Electrolysis Cell-assisted AD (MEC-AD). By introducing electrodes in conventional AD and applying a small potential, the oxidation of organic compounds on the bioanode is promoted and the CH_4 production is boosted through electromethanosynthesis on the biocathode (Kanellos et al., 2024).

In this context, the present study aims to evaluate the performance of a MEC-AD system, in comparison to conventional AD for the treatment of IPPW. The assessment focused on key performance parameters, including organic load removal and methane production.

2. Materials and Methods

2.1. Reactors setup

Two identical 2 L reactors were constructed, one used as the typical AD reactor and the other as the MEC-AD reactor, as described elsewhere (Kanellos et al., 2024). The reactors were kept in a temperature control box at 35 ^oC and their working volume was 1.8 L. A total of six electrodes (3 cm × 10 cm x 1 cm each), made from carbon felt, were inserted in the MEC-AD reactor. Three of them served as the bioanode and the other three served as the biocathode. Titanium wire was connected to the electrodes as the current collector and a DC power supply (DC PS-1502DD) was used to apply a constant voltage (1 V) on the MEC-AD reactor.

2.2 Reactors start-up, substrate and operation

Anaerobic Sludge (AS) was obtained from the Municipal Wastewater Treatment Plant of Lykovrisi, in Attica, Greece and served as inoculum for both reactors. The IPPW was obtained from the factory of PepsiCo Hellas S.A. & Tasty Foods S.A., in Attica, Greece, and it was supplied daily via draw-fill operation, at a HRT of 15 d. The physicochemical characteristics of the IPPW were: pH 6.8; alkalinity 0.2 (eqg_{CaCO3}/L); soluble COD 2.5 g_{O2}/L; total COD 2.8 g_{O2}/L.

2.3 Analytical methods

The analytical measurements (pH, alkalinity, total COD and soluble COD) were performed according to the standard methods for the Examination of Water and Wastewater. The biogas production was quantified using the oil displacement technique, as described elsewhere (Kanellos et al., 2024). The CH_4, CO_2 and H_2S content was measured using a portable gas analyzer (Gas Data - GFM436).

3. Results and Discussion

As can be seen in Fig.1a, the tCOD content in the MEC-AD reactor decreased from 30 to 15.3 g/L within the first seven days of operation, whereas the AD reactor exhibited a decrease from 30 to 21.9 g/L within the same period. Throughout the reactors' operation period, the MEC-AD achieved increased particulate organic content degradation rate by 0.02 g_{COD}/(L d). The improved removal of particulate solids led to an equivalent increase in the soluble organic content, as shown in Fig.1b. In particular, the MEC-AD reactor exhibited a steep increase in its sCOD content, from 0.2 to 1 g/L during the first seven days of operation, which was steadily decreased again to 0.2 g/L by the 25^{th} day of operation. On the contrary, the sCOD content of the AD remained at 0.2 g/L and increased to 1 g/L on the 35^{th} day of operation. Furthermore, the sCOD content in the AD reactor did not decrease to its initial value of 0.2 g/L until the 118^{th} day of operation. The results indicate that the applied potential was beneficial for the faster stabilization time of the MEC-AD process, relative to AD, which has been previously addressed (Kanellos et al., 2024). Moreover, the applied potential contributed to the hydrolysis of the particulate solids of the IPPW, which is the rate-limiting step for the AD process. Notably, throughout the reactors' operation period, the effluent from the MECAD reactor had lower values of tCOD than that of the AD reactor.

The improved hydrolysis of particulate solids led to an improved biogas production from the MEC-AD reactor, since the average volume produced was 0.2 L/d, relative to 0.02 L/d for the AD. In addition, the applied potential contributed to the improvement of the biogas composition, since the MEC-AD reactor achieved an average CH_4 production of 0.04 L/($L_{reactor}$ d), a threefold increase relative to the CH_4 production of the AD which was 0.013 L/($L_{reactor}$ d), shown in Fig.1c. Furthermore, the biogas produced from the AD reactor contained twice the H_2S concentration (104 and 53 ppm for the AD and the MEC-AD, respectively), which indicates the inhibition of methanogens in the AD reactor which act antagonistically to hydrogen sulfide producing bacteria (Mutegoa and Sahini, 2023).

4. Conclusions

Overall, the results imply that the potential application does not only contribute to the increased hydrolysis of particulate organic compounds and the faster oxidation of soluble organic compounds, but also to the enhanced biogas productivity and improved CH_4 content, by promoting the electromethanosynthesis reaction and suppressing the development of hydrogen sulfide producing bacteria.

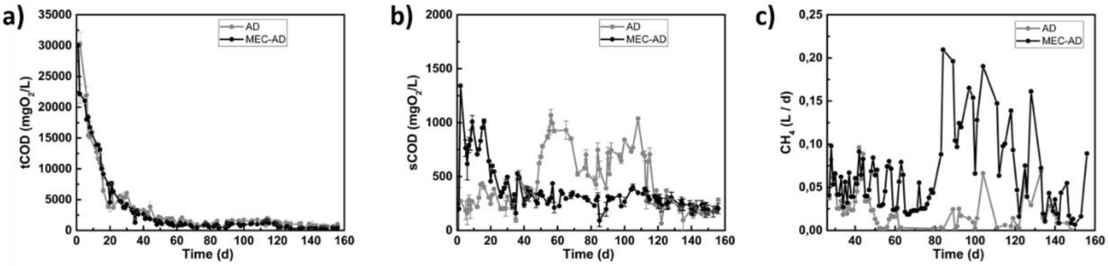

Figure 1. The a) tCOD, b) sCOD and c) CH_4 production, of the AD reactor and the MEC-AD reactors.

Acknowledgements: The research project "GREENUPGRADE: Valorization of green energy for enhancing the robustness and upgrading the performance of anaerobic digestion systems (61401400)" is implemented in the framework of H.F.R.I call "Basic research Financing (Horizontal support of all Sciences)" under the National Recovery and Resilience Plan "Greece 2.0" funded by the European Union – NextGenerationEU (H.F.R.I. Project Number: 15522).

References

Kot A.M, Pobiega K., Piwowarek K., Kieliszek M., Błażejak S., Gniewosz M., Lipińska E. (2020), Biotechnological Methods of Management and Utilization of Potato Industry Waste—a Review, *Potato Research*, **63**, 431–447.

Bouchareb R., Bilici Z., Dizge N. (2021), Potato Processing Wastewater Treatment Using a Combined Process of Chemical Coagulation and Membrane Filtration, *Clean – Soil, Air, Water*, **49**, 2100017.

Durruty I., Bonanni P.S., González J.F., Busalmen J.P. (2012), Evaluation of potato-processing wastewater treatment in a microbial fuel cell, *Bioresource Technology*, **105**, 81-87.

Monou M., Pafitis N., Kythreotou N., Smith S.R., Mantzavinos D., Kassinos D. (2008), Anaerobic co-digestion of potato processing wastewater with pig slurry and abattoir wastewater, *Journal of Chemical Technology and Biotechnology*, **83**, 1658–1663.

Zoutberg G.R. and Eker Z. (1999), Anaerobic treatment of potato processing wastewater, *Water Science and Technology*, **40**, 297-304.

Kanellos G., Tremouli A., Arvanitakis G., Lyberatos G. (2024), Boosting methane production and raw waste activated sludge treatment in a microbial electrolysis cell-anaerobic digestion (MEC-AD) system: The effect of organic loading rate, *Bioelectrochemistry*, **155**, 108555.

Mutegoa E. and Sahini M.G. (2023), Approaches to mitigation of hydrogen sulfide during anaerobic digestion process – A review, *Heliyon*, **9**, e19768.