СЕКЦИЯ 1
УСТОЙЧИВОЕ РАЗВИТИЕ МОГИЛЕВСКОЙ ОБЛАСТИ: ЧЕЛОВЕК-ПРИРОДА-ТЕХНОЛОГИИ

УДК 620

TOWARDS ELECTRO-FERMENTATIVE COMPOSTING PLANTS

Christian Abendroth, André Rückert, Hansjörg Bierwage, Christina Dornack

Technische Universität Dresden,
Institute for Waste Management and Circular Economy
(Dresden, Germany)
Christian.abendroth@tu-dresden.de

Abstract. Electro-fermentative approaches are well known in anaerobic digestion (AD) processes. Multiple scientific articles describe already the possibility of enhancing AD processes using conductive particles or even electrodes that are inserted into the process. Although the majority of articles about electro-fermentation address anaerobic processes, microbiomes from composting processes are susceptible to electrical current as well. However, and to the best of our knowledge, electroactive microbiomes in respect to composting processes are addressed only rarely. To give more attention to this topic, the present review summarizes multiple electro-fermentative approaches that help to optimize composting processes. Below the discussed approaches are the E-Fenton process, electric field-assisted aerobic composting, electro kinetic treatment and compost soil MFCs.

Introduction

Electro-active microorganisms have been discovered a long time ago and are described in relation to multiple biotechnological approaches. Typical examples that are often mentioned in the literature are microbial fuel cells (MFCs), as for example described in a review article by Palanisamy *et al.* 2019. Although a wide variety of MFC configurations are known, they typically consist of cathodes and anodes being inserted into residual bioactive substances, which in turn allow the generation of electricity. Since 2005 it is also known that electro-fermentative approaches allow for the production of hydrogen using so called microbial electrolysis cells (MECs). In such cells, biomass is converted into protons, electrons and carbon dioxide within an anode chamber. Via an ion exchange membrane, protons diffuse towards the cathode chamber. The cathode is usually covered with catalytic groups (e.g. platin), which facilitate the transfer of electrons on protons, resulting in the production of hydrogen.

Until now, multiple types of MECs have been described, and many of them are summarized in a recent review article by Kadier *et al.* (2016). As of late, scientists became interested in microbial electro activity within anaerobic digestion processes that yield methane. Especially the term direct interspecies electron transfer is of high interest.

With regard to this, it has been described that microorganisms are not only able to transfer electrons via indirect electron transfer (IIET) using electron carriers such as hydrogen or acetate, but also forming so called nanowires, which allow them to grow on conductive particles or to attach themselves directly on other cell surfaces in order to transfer electrons more directly (DIET). A general overview on DIET is given in a recent review article by Cheng and Call (2018).

Meanwhile, multiple conductive materials have been tested in anaerobic digester processes in order to improve methanation efficiency (Martins et al., 2018). Given the vast number of articles that are addressing electro-fermentative approaches in MFCs, MECs or anaerobic methanation, it surprises that this topic is seemingly underrepresented in relation to composting. To close this gap, the here presented work summarizes advancements, that were published in respect to electro-fermentative composting.

Enrichment of electroactive biofilms

The question for the usefulness of electric fermentation within composting processes raises also the question, whether an enrichment of electroactive organisms can be achieved in such systems. As a matter of fact, there are already articles describing the enrichment of such cultures. For example: in 2008, electrodes have been inserted into garden compost, and attached biofilms were analysed. To do so, Parot *et al.* compared the oscillation of electric current to a sterilized compost control and, additionally, epifluorescence microscopy was applied. Parot *et al.* described that the underlying biofilms were able to control current oscillations. Based on this observation, the applicability of chronoamperometry was evaluated as a useful methodology to identify electroactive microorganisms within such fermentation systems. Works such as the one from Parot *et al.* highlight the cultivability of electroactive microorganisms within aerobic environments. This leads to the question of whether this also has a positive effect on the composting process.

Fenton process

It was recently shown that the Fenton process can be combined with composting processes. In 2018, Khajouei *et al.* used the Fenton process to treat contaminated leachate from composting processes. The Fenton process is a catalytic reaction that facilitates oxidation processes applying iron salts and hydrogen peroxide in acidic media. In the work from Khajouei *et al.* additionally electrical current was applied (the so-called E-Fenton process). Different conditions were compared, finding the optimum at pH 3.0, 0.25 M H_2O_2 and applying an electrical current of 3 A. To evaluate the improvement in degradability, the ratio of biological oxygen demand to the chemical oxygen demand (BOD_5/COD) was analysed (biodegradability index). According to Khajouei *et al.*, the biodegradability index could be lowered from originally 0.60 to 0.31. As substrate municipal solid waste was applied.

Electric field-assisted aerobic composting

Inserting electrodes into composting processes allows the generation of an electric field which has a substantial effect on the process. Shangguan *et al.* (2018) used a thermoelectric generator (thermoelectric sheets) to generate a voltage between 8.8 – 18.6 V with power yields up to 7 W. To avoid voltage fluctuations, they applied a current-to-direct-current (DC-DC) voltage converter, which allowed a continuous output of 6 V. Such an electric field-assisted aerobic composting process allows optimizing the conventional composting process, while also generating a smaller amount of energy.

Electro kinetic treatment

Similar to the effect observed with the E-Fenton processes as described above, the addition of electrodes itself improves already the degradation efficiency. Electro kinetic treatment is a technique that is usually applied to contaminated land. Electrodes are inserted into collection wells. The electric field caused by the electrodes results in the migration of contaminants into the collection wells, where the electric potential of the electrodes facilitates their degradation (Iyer, 2001). It was highlighted in an article by Medina *et al.* (2014) that the process of electro kinetic treatment can be improved when mixing compost into the respective soils.

Electrical current generating compost cells

As described for the electric field-assisted aerobic composting by Shangguan *et al.* (2018), several other authors focus their works on the generation of electrical currents from compost. For example: Moqsut *et al.* (2015) built a paddy plant microbial fuel cells (PMFCs) that generated a voltage of up to 700 mV. For the experiments, soil filled buckets with rice plants were used. To generate an electric current, carbon fibre-based electrodes were inserted. Moqsut *et al.* observed the highest voltage when the soil was mixed with 1% of compost. Interestingly, they described higher voltages compared to controls without compost or without rice plants.

Another current study revealed a compost soil MFC (CSMFC) that was powered with urea (Magotra *et al.*, 2020). The addition of urea to compost increases the amount of nutrients, which in turn increases the power generation. The study from Magotra *et al.*, 2020 does therefore show the possibility to combine composting processes with power generation and utilization of wastewater.

Increased DIET due to supplements

In the field of anaerobic digestion, recent articles describe the possibility to increase direct interspecies electron transfers (DIET) applying conductive particles. A current review summarizes multiples works describing improvements in fermentation due to supplements such as magnetite or biochar (Martins *et al.*, 2018). DIET reduces electron transfers via hydrogen and other indirect electron carriers. Especially hydrogen works as an inhibitor for syntrophic degradation. It has recently been shown that an increased DIET due to the addition of carbon felt improved the syntrophic degradation of butyrate. The effects of DIET are usually described for anaerobic environments. However, one could imagine applying it also to environments with microaerophilic conditions. To the best of our knowledge, there are no articles that relate conductive particles or electron donors to compost yet. Although, a study by Aulenta et al. from 2020 features the possibility to improve degradation processes in contaminated soils by adding electron donors such as ethanol. Therefore, investigating the effect of electron donors on compost could be an interesting approach.

Construction supercapacitors from compost leachate

In respect to the growing field of bioeconomy, it is not only of interest to improve the degradability of compost facilities, but also to produce value added products. In this context, it should be emphasized that compost is not only suitable for electro fermentative processes, but that compost leachate is also a promising precursor for supercapacitors. Liu *et al.* (2020) applied compost leachate to hydrothermal carbonization followed by KOH activation. The highest specific surface area was achieved with activation at 700°C, reaching capacitance of 228 F g^{-1} at 0. 5 A g^{-1}.

Acknowledgements

We are grateful for funding of the work by the The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (grant number 16EXI4016A “BYGreen”). Moreover, we want to thank Isla Hodgkinson for proof reading of the article.

References

1. Aulenta, F, Tucci, M, Viggi CC, Dolfing J, Head IM, Rotaru AE; 2020. An underappreciated DIET for anaerobic petroleum hydrocarbon-degrading microbial communities. Microb Biotechnol. 0, 1 – 6.
2. Cheng Q, Call DF; 2016. Hardwiring microbes via direct interspecies electron transfer: mechanisms and applications. Environ. Sci.: Processes Impacts. 18, 968.
3. Liu Z, Tian D, Shen F, Nnanna PC, Hu J, Zeng Y, Yang G, He J, Deng S; 2020. Valorization of composting leachate for preparing carbon material to achieve high electrochemical performances for supercapacitor electrode. J Power Sources. 458, 228057.
4. Kadier A, Simayi Y, Abdeshahian P, Azman NF, Chandrasekhar K, Kalil MS; 2016. A comprehensive review of microbial electrolysis cells (MEC) reactor designs and configurations for sustainable hydrogen gas production. Alexandria Engineering Journal. 55, 427 – 443.
5. Khajouei G, Mortazavian S, Saber A, Meymian NZ, Hasheminejad H; 2018. Treatment of composting leachate using electro-Fenton process with scrap iron plates as electrodes. *Int. J.* Environ. Sci. Technol. 16, 4133 – 4142.
6. Magotra VK, Kumar S, Kang TW, Inamdar AI, Aqueel AT, Im H, Ghodake G, Shinde S, Waghmode DP, Jeon HC; 2020. Compost Soil Microbial Fuel Cell to Generate Power using Urea as Fuel. Sci Rep. 10, 4154.

7. Martins G, Salvador AF, Pereira L, Alves MM. Methane Production and Conductive Materials: A Critical Review. Environ Sci Technol. 52, 10241 – 10253.
8. Medina, ID, Bustos, EB, León MT; 2014. Compost Aided Electrokinetic Remediation of an Hydrocarbon Polluted Soil. J Mex Chem Soc. 58, ISSN 1870-249X.
9. Moqsud MA, Yoshitake J, Bushra QS, Hyodo M, Omine K, Strik D; 2015. Compost in plant microbial fuel cell for bioelectricity generation. Wate Management. 36, 63 – 69.
10. Palanisamy G, Jung HY, Sadhasivam T, Kurkuri MD, Kim SC, Roha SH; 2019. A comprehensive review on microbial fuel cell technologies: Processes, utilization, and advanced developments in electrodes and membranes. J Clean Prod. 221, 598 – 621.
11. Parot S, Délia ML, Bergel A; 2008. Forming electrochemically active biofilms from garden compost under chronoamperometry. Bioresour Technol. 99, 4809 – 4816.
12. Iyer R; 2001. Electrokinetic Remediation, Particul Sci Technol. 19, 219-228.
13. Shangguan H, Fu T, Wu J, Tang J, Zeng RJ, Zhou S; 2020. Use of an in situ thermoelectric generator for electric field-assisted aerobic composting. Sci Total Environ. 140618.
14. Zhang M, Ma Y, Dandan J, Xueyuan L, Zhang J, Zang L; 2019. Synergetic promotion of direct interspecies electron transfer for syntrophic metabolism of propionate and butyrate with graphite felt in anaerobic digestion. Bioresour Technol. 287:121373.