# Coupling anaerobic digestion and electrooxidation for sustainable waste treatment: a review

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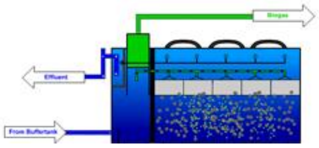
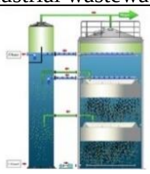
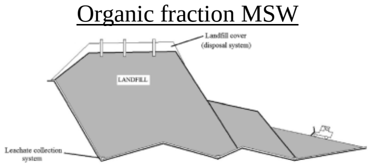
Anaerobic digestion facilities are gaining increasing popularity for organic waste processing and valorisation. They are mainly used for the treatment and biogas production, from municipal and industrial wastewaters, sewage sludge, agricultural and other organic by-products. However, the most important problems associated with different anaerobic reactor technologies (see Table 1) include: (a) low biogas production (that may affect the economic feasibility), (b) major odour nuisances, and (c) a digestate with high ammonia content, pathogenic microorganisms, and organic content (often recalcitrant or low degradability) that require further processing. These issues can be overcome by the combination of anaerobic digestion and electrooxidation technologies.

**Table 1.** Summary of typical problems encountered during the anaerobic treatment of different wastes types.

| Waste type | Anaerobic digestion facilities |
|---|---|
| Municipal wastewater   | • Major odour nuisances from the anaerobic effluent<br>• Effluent organic content restrictive for disposal or reuse<br>• High ammonia and phosphorus in the effluent<br>• Low removal of pathogenic microorganisms<br>• Low removal of persistent organic chemicals<br>• Post-treatment required such as activated sludge or polishing ponds |
| Agricultural and organic wastes  | • Major odour nuisances from digestate storage and application<br>• Problems with low biogas production<br>• Large quantities of digestate and land requirements<br>• Low removal of pathogenic microorganisms<br>• High ammonia content in the digestate<br>• Digestate with organic content of low degradability (lignocellulosic, polyphenolic, natural colours / pigments, etc) |
| Industrial wastewaters  | • Residual surfactants from washing and cleaning operations<br>• Reactor instabilities from fat oil and grease, and particulate organic matter<br>• Complex post-treatment systems such as activated sludge, ultrafiltration and reverse osmosis |
| Sewage sludge  | • Problems with low biogas production (depending on sewage sludge SRT)<br>• Digested sludge with poor dewaterability<br>• High ammonia content in the digester supernatant<br>• Low removal of pathogenic microorganisms<br>• Digested sludge questionable for soil conditioner (persistent organics, metals) |
| Organic fraction MSW   | • Low biogas production and diffuse emissions from landfill bioreactors<br>• Leachate with organic content of low biodegradability<br>• Ammonia<br>• Heavy metals<br>• Recalcitrant organics |

Conventional treatment systems (such as polishing ponds, activated sludge, reverse osmosis) are not capable of removing recalcitrant organic compounds, ammonia concentrations and pathogenic microbes from digested effluents. Moreover, they are complex, entail a high capital cost and generate residues (such as biosolids, reverse osmosis concentrates) that require further processing. Electrochemical methods have been applied successfully to degrade different organic pollutants and disinfect wastewaters. Indeed, the integration of advanced oxidation technologies and biological processes, has been recognized as a promising approach for biogas production from low biodegradability substrates, such as olive mill effluents, sewage sludge, lipids and lignin (see Table 2). Many industrial wastewaters such as pulp and paper, slaughterhouse, cheese whey, baker's yeast and poultry effluents have also been successfully treated (Table 2). Boron-doped diamond electrodes were reported efficient for the degradation of refractory or priority pollutants such as ammonia, cyanide, phenol, chlorophenols, aniline, various dyes, surfactants, alcohols and other compounds (Alfaro et al., 2006). Electrooxidation was also efficient for fouling minimization in membrane bioreactors (Ibeid et al., 2013). Finally, electrochemical oxidation can be easily controlled, is robust and simple, offers in-situ generation of oxidants and does not involve the use of chemicals.

The proposed review will focus on the above mentioned issues and the potential applications of electrooxidation as a mean to improve performance and minimize the environmental footprint of anaerobic digestion facilities.

**Table 2.** Performance of electrooxidation processes in combination with anaerobic treatment systems.

| Waste type | Performance | Reference |
|---|---|---|
| Olive mill wastewater (pre-treatment) | Oxidation in the presence of solids resulted in a substantial solid fraction being dissolved. COD soluble increased by 60-70%. | Kotta et al., 2007 |
| Sewage sludge (pre-treatment) | Electrooxidation was used to solubilize organic matter and increase biogas production from sewage sludge | Barrios et al., 2017 |
| Oleic acid (pre-treatment) | Electrochemically pre-treated oleic acid resulted in significantly higher methane yield during anaerobic digestion | Goncalves et al., 2006 |
| Lignin (pre-treatment) | Conversion of lignin and chemical yields depend mainly on the applied current density and the electrode material | Parpot et al., 2000 |
| Cheese whey (digested) | Complete removal of COD was achieved within 3-4 h of reaction time | Katsoni et al., 2014a |
| Slaughterhouse wastewater (digested) | COD removal 67% was achieved after electrooxidation | Vidal et al., 2016 |
| Municipal wastewater (digested) | An EGSB removed soluble organics from municipal wastewater and the electrochemical reactor oxidized the remaining ammonia | Dai et al., 2011 |
| Baker's yeast wastewater (digested) | Complete color and COD removal was achieved after ~3 h of oxidation. | Liakos et al., 2017 |
| OFMSW (digested) | A combined electro-coagulation and electrooxidation process recorded a removal efficiency of 95% for COD and 44% for $NH_4$-N | Fernandez et al., 2017 |
| Table olive wastewater (pre-treatment) | Up to 80% of phenolic compounds were removed and biogas production was possible compared to non-oxidized wastewater | Marone et al., 2016 |
| Olive mill wastewater (digested) | Electrooxidation achieved complete COD removal within 7 h | Katsoni et al., 2014b |
| Olive mill wastewater (digested) | Electrooxidation promoted selected oxidation of phenols and color removal. | Goncalves et al., 2012 |
| Toilet wastewater | Complete disinfection, elimination of ammonia and COD removal ~90% was achieved during toilet wastewater treatment | Huang et al., 2016 |
| Poultry manure (digested) | 2 h electrochemical treatment reduced NH4-N = 57%, TP = 76% and TOC = 72% | Wang et al., 2016 |
| Paper mill wastewater | Sulfide in paper mill wastewater was removed with low current density. Bacteria inactivation was also achieved | Sarkka et al., 2009 |
| Sewage sludge | Improved dewaterability and stabilization of wastewater sludge and the advantage of simultaneous disinfection (4-5 log) and odor removal | Bureau et al., 2012 |
| Landfill leachate | Ammonia removal from landfill leachate was possible within 6 h electrooxidation | Cabeza et al., 2007 |

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