Enhanced biomethane production from food waste in a bio-electrochemical anaerobic digester (BEAD)

B. Tartakovsky[1], V. Singh[1], H. Li[2], B. Ormeci[1], A. Hussain[1]

[1]National Research Council of Canada; 6100 Royalmount Ave, Montreal, QC, Canada H4P 2R2
[2]Carlton University, 1125 Colonel By Drive, Ottawa, ON, Canada K1S 5B6
Keywords: Food Waste; Biomethane; Bioelectrochemical System; Microbial Electrolysis
Presenting author email: Boris.Tartakovsky@nrc-cnrc.gc.ca

The disposal of food waste in Canada contributes to a significant 20% of the country's total methane emissions, with Canadian provinces collectively investing an astonishing $200-400 million annually in waste and landfill management. This dual challenge of environmental and economic concern has prompted urgent attention, especially in light of nationwide plans to entirely redirect the organic waste fraction from landfills by 2030-2040. In response to this pressing need, there is a growing interest in exploring innovative and sustainable solutions for effective food waste management.

Anaerobic digestion (AD) is an excellent technology for treating waste streams with high organic content such as food waste. However, CH_4 yields for conventional AD processes are much lower than the theoretical value of 0.35 L_{CH4}/gCOD. Also, AD operation requires relatively high temperatures (35-40°C), which greatly limits its feasibility in colder regions. To address these challenges, new AD-based waste-to-energy technologies have emerged. One such advancement is the bioelectrochemical anaerobic digestion (BEAD) technology, which extends beyond conventional methanogenic pathways by introducing additional CH_4 production routes. BEAD for methane recovery from food waste is in early stages of development. Studies so far have primarily tested BEAD on synthetic food waste or non-acidified food waste, which is not only impractical but also results in low methane yields. Hence, this study was performed to address a critical research and development gap, i.e., BEAD operation and optimization on real hydrolysed and acidified food waste.

The BEAD reactor assembled for this study was made of a glass column with an approximate liquid volume of 0.5 L. Conductive bio-rings were used as electrodes (anode and cathode). IrO_2 coated titanium meshes was inserted in the middle of the anodic and cathodic compartments and served as the current collector (Fig 1). The applied voltage for the BEAD was fixed at 1.4 V. The performance of the BEAD was compared to a Control-AD reactor, which was similar in volume to the BEAD but lacked power supply and was packed with plastic media for microbial attachment.

BEAD and the Control-AD were inoculated with granular anaerobic sludge. Both reactors were continuously fed with food waste leachate obtained from a dry fermentation (leach-bed) reactor system. The soluble Chemical Oxygen Demand (sCOD) of the leachate varied between 34-36 g L^{-1}. The organic loading rate during reactor operation ranged from 2 to 12 g /L_R d)$^{-1}$ for both reactors. This organic load was obtained by adjusting the influent flow rate. For both systems, the temperature and pH were maintained at 22°C and 7, respectively.

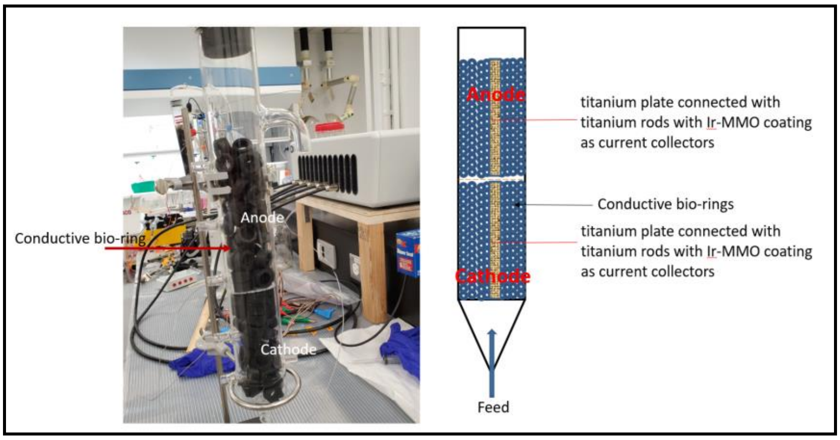

Figure 1. BEAD reactor used in this study.

Table 1 summarizes the performance of the BEAD and Control-AD systems fed with the food waste leachate at different OLRs. The daily CH_4 production (L d^{-1}) and the yield (L $g^{-1}_{COD\ removed}$) for BEAD was consistently higher than the Control-AD. The difference in methane production between the BEAD and Control-AD was more pronounced at higher OLRs (above 7 g (L $d)^{-1}$), e.g. 20% at an OLR of 8 g (L $d)^{-1}$ and 10% at an OLR of 3-4 g (L $d)^{-1}$. No considerable difference was observed in COD removal efficiency, which for BEAD remained above 87% even at the highest organic load of 12 g (L $d)^{-1}$ and above 83% for Control-AD at an organic load of 10 g (L $d)^{-1}$. Such high COD removal efficiencies with higher methane yields in the BEAD system suggest the presence of concurrent methane production pathways in the BEAD system. This hypothesis is further corroborated by decreased methane yield of the BEAD system under zero applied voltage. Stopping the voltage supply at OLR of 3 g (L $d)^{-1}$ reduced the methane yield in BEAD from 0.29 to 0.26 L/g. This value was still higher than the Control-AD (0.24 L/g), apparently due to improved biofilm retention in BEAD. Interestingly, hydrogen gas was detected in the Control-AD at higher OLRs, while no hydrogen gas was detected in BEAD (Table 1). This observation suggests abundance of hydrogenotrophic methanogens in BEAD, implying that the conversion of H_2 and CO_2 to methane contributed to higher methane yields in BEAD along with other pathways, in agreement with the expected bioelectrochemical reactions at the BEAD cathode. Overall, the BEAD system showed stable performance at organic loads up to 12 g (L $d)^{-1}$, while the Control-AD failed at loads above 10 g(L $d)^{-1}$, implying not only higher methane yields, but also improved BEAD stability at high OLRs.

Table 1. Performance of BEAD and Control AD at different organic loading rates. BEAD was operated at applied potential of 1.4 V. Notations: RE – removal; OLR – organic loading rate (g-sCOD added per liter reactor volume per day); SCFA RE – short chain fatty acids removal efficiency. CH_4 yield is given in L per g sCOD removed.

BEAD PERFORMANCE

OLR g (L $d)^{-1}$	sCOD removal %	SCFA RE %	Biogas L d^{-1}	CH_4 %	H_2 %	CH_4 yield (L g^{-1}	HRT days	Current mA
3	98.0	98.7	0.83	67.8	ND	0.29	5.0	2.6
4	96.5	96.9	1.19	67.0	ND	0.31	5.0	3.2
5	94.8	95.7	1.55	63.6	ND	0.32	5.0	3.8
6	94.2	95.7	1.96	62.0	ND	0.33	5.0	4.7
7	93.9	95.2	2.33	61.8	ND	0.34	5.0	5.9
8	93.3	95.1	2.78	61.7	ND	0.35	4.3	6.3
9	92.4	94.5	3.11	61.3	ND	0.35	3.8	5.3
10	92.0	92.5	3.41	60.8	ND	0.35	3.4	5.7
11	89.4	91.3	3.69	60.0	ND	0.35	3.1	5.9
12	87.2	90.1	3.80	59.4	ND	0.34	2.9	5.5
3*****	94.4	96.7	0.77	63.8	ND	0.26	5	NA

****** BEAD performance at zero applied voltage*

CONTROL-AD PERFORMANCE

OLR g (L $d)^{-1}$	sCOD removal %	SCFA RE %	Biogas L d^{-1}	CH_4 %	H_2 %	CH_4 yield (L g^{-1}	HRT days
3	97.0	97.8	0.75	60.5	ND	0.24	5.0
4	96.2	95.8	1.09	59.2	ND	0.26	5.0
5	92.7	93.6	1.50	58.3	ND	0.29	5.0
6	92.9	94.0	1.83	57.7	ND	0.29	5.0
7	91.1	92.1	2.18	57.6	ND	0.30	5.0
8	90.2	91.0	2.38	57.1	0.2	0.30	4.3
9	86.7	90.8	2.56	56.8	0.9	0.29	3.8
10	83.1	87.2	2.69	55.5	1.4	0.28	3.4

***Note**: Control AD failed at organic loading rates above 10 g (L $d)^{-1}$*