Combining photosynthetic microbial fuel cell with photobioreactor for bioenergy recovery from anaerobically digested effluent from food waste

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Introduction: Food waste constitutes a large component (30–50%) of municipal solid wastes. Anaerobic digestion has been proved to be an effective technology to manage food waste and also produce bioenergy resources like methane [Li et al., 2013]. However, anaerobically digested effluent from food waste (ADE-FW) is still of severe environmental concern for its high concentration of nutrients and organic substances.

Photosynthetic microbial fuel cell (PMFC), which uses an algae-assisted cathode, is a promising technology for bioenergy recovery and wastewater treatment. But a large proportion of the nutrients (NH_4^+-N) in the ADE-FW need to be polished further. Therefore, a system combining a tubular PMFC and two photobioreactors (PBRs) was developed in this study. The PMFC was used to produce electric energy and algae biomass, as well as organic matter and nutrients removal. PBRs were used to polish the effluent from the PMFC. Algal lipid accumulation could also be achieved due to the nutrients limited environment in the PBRs [Rodolfi et al., 2009].

Material and methods: A tubular PMFC and two identical PBRs that used in this study are shown in Fig.1. The cathode chamber (1.5 L) consisted of a cylindrical section joined to a conical section, and also functioned as an algal bioreactor. The tubular anodic chamber had ten rectangular holes for cation exchange between anolyte and catholyte. A cation exchange membrane (CEM) was wrapped around the tubular anodic chamber to separate the anodic and cathodic chambers, and then a layer of carbon cloth was wrapped around the CEM to function as the cathode. The PBRs consisted of a cylindrical section joined to a conical section and had a work volume of 2.5 L.

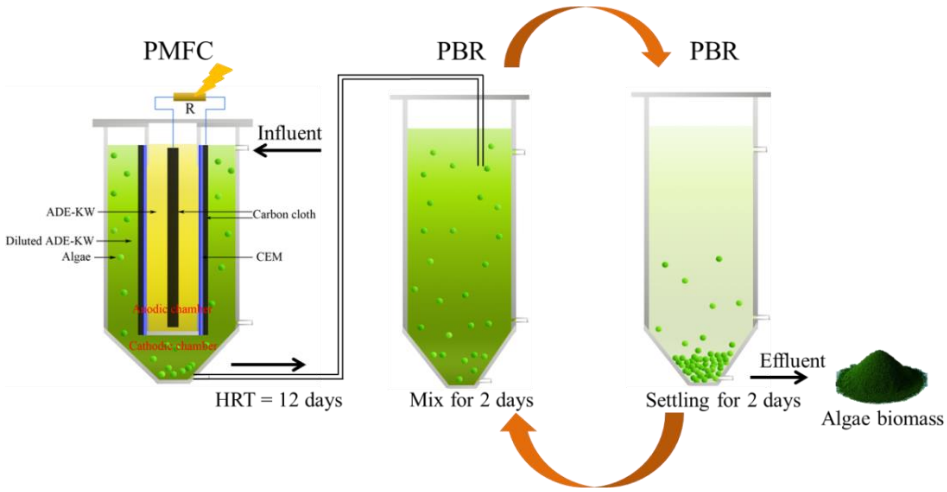

Figure 1. Schematic of combination of PMFC and PBRs for energy recovery from ADE-FW treatment.

The anolyte of the PMFC was the ADE-FW and it was not replaced by any fresh ADE-KW during the whole experiment. The catholyte of the PMFC, also functioned as algal culture, was 4% ADE-FW. The 4% ADE-FW was fed into the catholyte of the PMFC continuously, resulting in a hydraulic retention time of 12 days. Then the effluent from the cathodic chamber flowed into a PBR and polished in the PBR for 2 days. After that, the PBR was left for two days for algae settling and algal lipid accumulation. At the same time, the other identical PBR was used to receive the effluent from the cathodic chamber. The algal culture in the PBRs is the BG11 medium that without any nitrogen or phosphorus source.

As a control, another PMFC (without combination with PBRs) was operated in batch modes. The majority of the algae biomass in the catholyte was harvested every 12 days and the culture was also replaced by fresh 4% ADE-FW every 12 days.

Results and discussions: The algae biomass was 0.7 g/L in the PMFC with continuous operation (PMFC-C), about 35% higher than that in the PMFC with batch operation (PMFC-B) (Fig. 2). The lipid content in the algae that harvested from PBRs was about 30.9%, resulting in an average lipid productivity of about 9.5 mg/(L·d). The lipid productivity of PMFC-B was 5.8 mg/(L·d) with a lipid content of about 26.7%. There was about 1.1 g algal biomass remained in PMFC-C on the 36th day. Therefore, the lipid productivity of the whole system with continuous operation was about 15.3 mg/(L·d).

The highest power density of PMFC-C was over 3 W/m^3. The power density decreased rapidly in the PMFC-B during each phase due to the decrease of cathode potential. The decrease of dissolved oxygen concentration in the catholyte is the main reason for the decrease of the cathode potential (data not shown).

The COD removal efficiencies (initial COD: 6534 mg/L) in the anodic chamber of PMFC-C and PMFC-B were 77% and 74%, respectively. The NH_4^+-N in the anolyte could transfer into catholyte through cation exchange membrane, resulting in a NH_4^+-N removal efficiency of 93.3% in the anolyte of PMFC-C. After transferred into catholyte, these NH_4^+-N would be assimilated by algae or oxidized to nitrite or nitrate. Nitrite and nitrate could be removed as electron acceptors at the cathode. The remained nitrogen in the catholyte would be polished in the PBR.

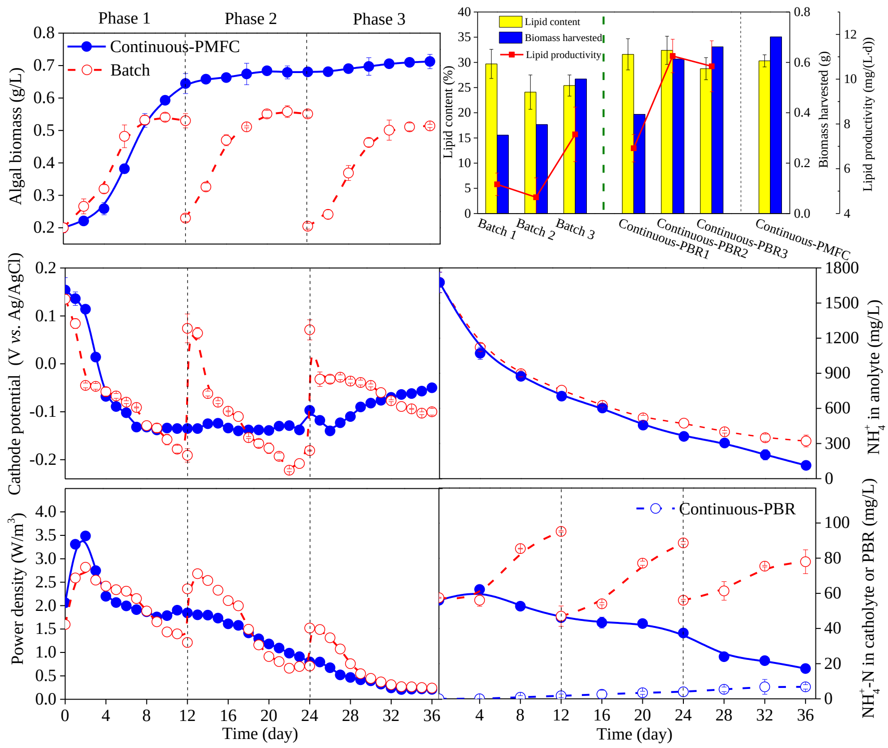

Figure 2. Algal biomass, power generation and NH_4^+-N removal in PMFC-C, PMFC-B and PBRs.

Conclusion: The lipid productivity of the whole system reached 15.3 mg/(L·d) and highest power density was about 3.0 W/m^3. About 93% ammonium in the anolyte transferred to the catholyte through the cation exchange membrane, and then removed in the cathodic chamber or PBRs. The combination of PMFC with PBR is a practical and efficient way to recover energy from ADE-FW.

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