WEC for WC: wastewater electrolysis cell for toilet wastewater reuse and hydrogen production

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A Photovoltaic-Powered Wastewater Electrolysis Cell (PWEC) may prove to be a promising energy conversion approach by hydrogen production and reduction of energy consumption for the existing sanitation facilities by on-site wastewater reuse. Electrochemical water oxidation to oxygen on metal oxides anodes has long been believed to initiate by formation of physisorbed hydroxyl radicals and/or chemisorbed active oxygens, which can be used for direct oxidation of environmental pollutants. The ubiquitous chloride in the wastewater often mediates indirect oxidation by reactive chlorine species (Cl•, Cl_2, and conjugate species) production, reducing specific energy consumption. The solar energy conversion by complementing hydrogen production on cathodes would cause a negligible carbon footprint when compared to the conventional methane-steam reformation. Therefore, the PWEC can be a potential breakthrough towards the world challenge for energy, water, and human health by using green chemistry without external chemical dosage. This study investigated a wastewater electrolysis cell (WEC) for the process optimization based on kinetic information.

The WEC with one compartment-three electrodes configuration consisted of bismuth oxide doped titanium dioxide (BiO_x/TiO_2) anode, stainless steel cathode and Ag/AgCl/Sat. KCl reference electrode. The anode was prepared by a thermal decomposition method, whose onset potential of water oxidation appeared to be 1.2 V (NHE) in circum-neutral pH. A repetitive cyclic voltammetry in 50 mM NaCl showed a decrease in the current onset potential owing to the chlorate formation. Wide range Tafel analysis under variable chloride concentration (10 – 50 mM) suggested that surface bound hydroxyl radical formation is the rate limiting step under anodic potentials (E_a) below 2.5 V (NHE).

Increasing the E_a above 3 V (NHE) resulted in a significant increase of the *iR* drop, higher Tafel slope, and a decrease in energy efficiency. Current variation under stepwise increase of acetate and chloride further showed that a direct oxidation by surface bound hydroxyl radical is negligible and the reaction between active oxygen (saturated active sites) and chloride is rate determining for current generation at E_a of 3 V (NHE). Consequently, the chloride concentration, rather than the *iR*-compensated anodic potential, was the major determinant of current efficiency for free chlorine generation.

The WEC experiments in model septic effluent ([COD] = 459 mg/L, [Cl^-] = 32.5 mM, electrolyte volume 55 mL, effective electrode surface = 5.4 cm^2, E_a = 3 V NHE) showed a quasi-constant current efficiency for degradation of COD (chemical oxygen demand), TN (total nitrogen) and ammonium as well as the formation of nitrate and chlorate. The psudo-first order decay rate was in the order of protein, COD, TN and ammonium (Fig. 1). Consequently, the COD, measureable protein, and color were eliminated almost completely within 6 hr of electrolysis, allowing the treated water suitable for unrestricted urban reuse. Hydrogen was generated with current efficiencies of 80 – 90%, while the hydrogen occupied as high as 60% of the total gaseous product (Fig. 2). The energy conversion efficiency of 25% was somewhat lower than an idealized electrolyzer, due to intrinsic overpotential, ohmic drop and side reactions in the adulterated solution. However, the energy loss would be compensated by saving energy for existing water treatment.

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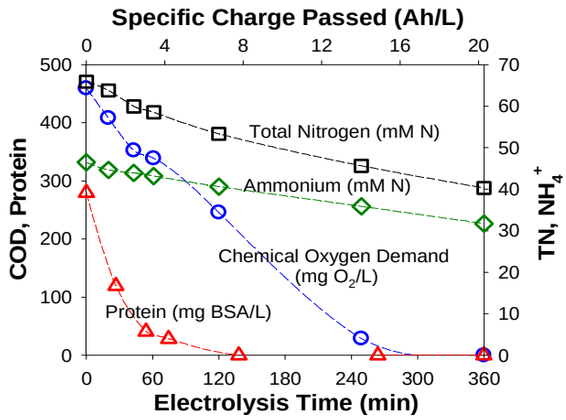

Fig. 1. Evolution of COD, protein, TN, and NH_4^+ concentration during electrolysis in model septic tank effluent (Urine + domestic wastewater (1:3) with 2 days of anaerobic digestion at 35°C)

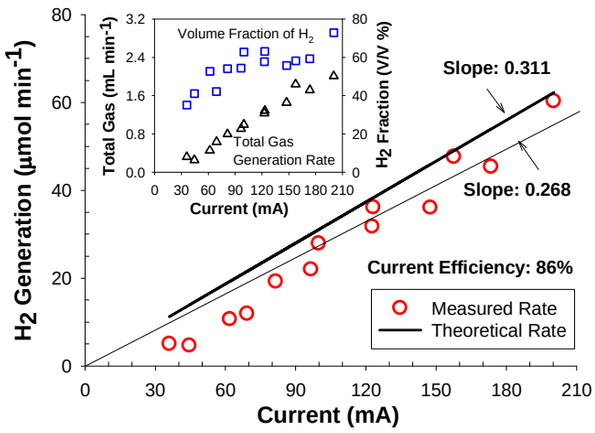

Fig. 2. Total gas and hydrogen generation rate under variable current in model septic tank effluent.