Proof-of-concept for renewable energy from organic pollutant degradation using hybrid electrolytic hydrogen and oxygen cells

Maiara Barbosa Ferreira[1], Gerffeson Almeida Moura[2], Herbet Lima Oliveira[1], Amanda D. Gondim[1], Livia N. Cavalcanti[1], Fabíola Correia de Carvalho[2], Edney R. Viana Pinheiro Galvão[3], Marco Quiroz[1], Elisama Vieira Dos Santos[1], Carlos A. Martinez-Huitle[1]

[1]Renewable Energies and Environmental Sustainability Research Group, Institute of Chemistry, Federal University of Rio Grande do Norte, Campus Universitário, Av. Salgado Filho 3000, Lagoa Nova, CEP 59078-970, Natal, Rio Grande do Norte, Brazil
[2]Instituto SENAI de Inovação em Energias Renováveis, Avenida Capitão Mor Gouveia, 2770, Lagoa Nova, CEP 59063-400, RN, Brazil.
[3]Departament of Petroleum Engineering, Federal University of Rio Grande do Norte, Av. Salgado Filho 3000, Lagoa Nova, CEP 59.078-970, Natal, RN, Brazil

Resumo/Abstract (Helvética, tam. 12)

RESUMO - Sistemas de eletrólise híbrida que utilizam compostos de sacrifício ou águas residuais complexas para gerar hidrogênio verde e produtos com valor agregado podem ser uma alternativa adequada. Desenvolvimento de um sistema de geração de energia limpa por meio de uma célula a combustível de hidrogênio-oxigênio a partir de um sistema eletrolisador híbrido PEM é possível. A prova de conceito foi utilizar o hidrogênio verde produzido por H_{CELL} (BDD|polluted H_2O||clean H_2O|Ni-Fe) acoplado em série a duas minicélulas a combustível de hidrogênio-oxigênio (F_{CELL}). O gás hidrogênio do H_{CELL} passou pela câmara anódica do F_{CELL} e as câmaras catódicas do F_{CELL} foram alimentadas com oxigênio do O_{CELL}, gerando uma potência de 0,4W e descontaminado a água em 99%.
Palavras-chave: Hidrogênio Verde, Oxidação Eletroquímica, Uso de Hidrogênio, Tratamento de Águas.

ABSTRACT - Hybrid electrolysis systems using sacrificial compounds or complex wastewater to generate green hydrogen and value-added products can be a suitable alternative are possible. Development of a clean energy generation system by means of a hydrogen-oxygen fuel cell from a hybrid PEM electrolyzer system. The proof-of-concept was to use the green hydrogen produced by H_{CELL} (BDD|polluted H_2O||clean H_2O|Ni-Fe) coupled in series to two hydrogen-oxygen mini fuel cells (F_{CELL}). Hydrogen gas from H_{CELL} was passed through the anode chamber of F_{CELL} and the cathode chambers of F_{CELL} were fed by oxygen from O_{CELL}, generating 0.4 W and 99% of depollution of water.
Keywords: Green Hydrogen, Electrochemical Oxidation, Hydrogen Use, Water Treatment

Introdução

The increasing global population and urbanization have led to an increase in the consumption of harmful pollutants and energy demands. Renewable energy sources are becoming essential for population and technological development, focusing on environmental preservation and non-depletion. Hybrid electrolysis systems using sacrificial compounds or complex wastewaters to generate green hydrogen and value-added products can be a suitable alternative. This method reduces the energy required to produce hydrogen, and PEM cells are commonly used to produce high-purity hydrogen gas, which can be fed into hydrogen-oxygen fuel cells (L. Oliveira et al., 2024; Yang et al., 2019). The present work aims to develop a clean energy generation system by means of a hydrogen-oxygen fuel cell from a hybrid PEM electrolyzer system.

Experimental

All reagents were high purity and supplied by Sigma Aldrich (Brazil). All solutions were prepared with ultrapure water (resistivity ≥ 18 MΩ cm). Figure 1 presents a comprehensive illustration of the hybrid-integrated cell concept with online supply of H_2 to fuel cell for the entire experimental apparatus. Chemical oxygen demand (COD) and total organic carbon (TOC) are performed as described elsewhere (Campos da Paixão et al., 2023; Cardozo et al., 2023; M. de Araujo et al., 2024). COD removal, total current efficiencies (TCE, in %) and energy consumption (EC) were estimated by using equations reported elsewhere (Brillas & Martínez-Huitle, 2015). Multiple experiments and analyses were replicated to minimize experimental error, with a confidence level of >95% for all determinations. The electrical power supply of the electrochemical reactors was provided by a photovoltaic (PV)-battery system (Figure 1), which is described in detail elsewhere (Barreto et al., 2024).

Figure 1. Scheme of the hybrid-integrated wastewater treatment system with clean energy production.

Resultados e Discussão

Experimental tests using two divided electrochemical reactors, composed of cathode and anode compartments, separated by a cation exchange membrane with a boron-doped diamond electrode (BDD) as anode (16 cm^2) and a stainless-steel mesh (based on SS, Ni-Fe) as cathode, in the case of the integrated-hybrid oxidation-hydrogen generation cell (H_{CELL}). For the oxygen generation cell (O_{CELL}), a DSA (16 cm^2) was used as anode and a stainless-steel mesh (SS, Ni-Fe based) as cathode, was used. The proof-of-concept experiments were conducted for 60 min, with a constant current of 1 A, and the electrochemical reactors were coupled in series to two hydrogen-oxygen mini fuel cells (F_{CELL}) with dimensions (20 cm × 29.7 cm × 15.5 cm), maximum parallel voltage of 0.9 V, and nominal power of 1.7 W. Hydrogen gas from H_{CELL} was passed through the anode chamber of F_{CELL} and the cathode chambers of F_{CELL} were fed by oxygen from O_{CELL}. The system was able to light a 2 V incandescent lamp, from a constant power of 0.3 W that was maintained from the initial instant until 2 min after the complete shutdown of the electrochemical system. The experimental tests were performed with synthetic solutions containing 0.5 M Na_2SO_4 as the supporting electrolyte for both reactors, and samples were collected at predetermined time intervals (10, 20, 30 and 60 minutes) and sent for UV-Vis and HPLC analysis to verify the degradation of the compound in question and corroborate the efficiency of the system (see Figure 2, COD and TOC removals).

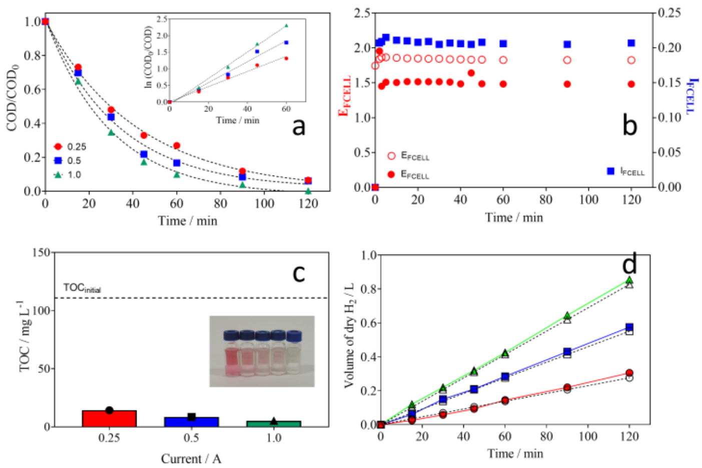

Figure 2. Relevant results: (a) Decay of normalized COD. Inset kinetic analysis, (b) potential and current produced by fuel cells when traditional water splitting is used or green H_2 produced when O_{CELL} is used, (c) TOC removal (inset: decolorization achieved), and (d) green H_2 production.

Conclusões

The real water samples were contaminated with 20 ppm of methyl red, as organic compound model, and these were also subjected to the tests, producing a constant power of 0.4 W, demonstrating promising results for the use of complex real waters for the generation of clean energy from the electrochemical treatment of these wastes, as a proof-of-concept.

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