Área: FIS

Electrochemical valorization of rice agro-industrial effluents for sustainable hydrogen production

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Highlights

Simultaneous green hydrogen production and rice wastewater remediation.
Low-cost stainless-steel electrodes enable sustainable energy and environmental recovery.
Electrochemical validation for dual energy–environmental applications.
Towards industrial scalability with eco-efficient hydrogen technologies.

Abstract

Anthropogenic global warming, evidenced by the rise in average global temperature, represents one of the most pressing threats to contemporary society. This scenario has driven the Paris Agreement to demand drastic reductions in CO_2 emissions and has stimulated global investments in sustainable hydrogen as an alternative to fossil fuels, which are responsible for approximately 75% of total emissions. Simultaneously, agro-industrial processing — exemplified by rice parboiling — generates effluents with high concentrations of organic matter, nitrogen, and phosphorus. Their improper disposal intensifies the degradation of aquatic ecosystems and contributes to N_2O emissions, a greenhouse gas nearly 270 times more potent than CO_2. In this context, the aim of this study is to investigate the feasibility of the simultaneous production of sustainable hydrogen and treatment of parboiled rice effluent, employing commercial 304 stainless steel (StSt-304) and platinum electrodes. For this purpose, a simulated effluent (SE) composed of 0.1 M Na_2SO_4 solution acidified to pH 4.0 and the raw effluent (RE) collected from a parboiled rice agroindustry were used. Electrochemical tests were carried out in a three-electrode electrochemical cell (StSt-304 as working electrode, Pt as counter electrode, and Reversible Hydrogen Electrode – RHE – as reference electrode). Electrochemical characterization was performed using Electrochemical Impedance Spectroscopy (EIS) to assess system resistance, Linear Voltammetry (LV) to determine Tafel parameters of the Hydrogen Evolution Reaction (HER), and Chronoamperometry (CA) to quantify H_2 production. The remediation efficiency of the parboiled rice effluent was evaluated by measuring Chemical Oxygen Demand (COD) before and after 1 hour of electrochemical treatment under a constant potential of −2.0 V vs. RHE, following Standard Methods 5220 D (Closed Reflux Colorimetric Method). Chronoamperometric tests performed at −2.0 V vs. RHE for 1 hour revealed current densities of 5.8 $mA \cdot cm^{-2}$ (SE) and 1.4 $mA \cdot cm^{-2}$ (RE) for the StSt-304/Pt configuration, corresponding to estimated H_2 production rates of 2.4 $mL \cdot h^{-1} \cdot cm^{-2}$ and 0.6 $mL \cdot h^{-1} \cdot cm^{-2}$, respectively. EIS analysis showed that the StSt-304/Pt system in SE exhibited a total resistance (R_t) of 2.4 $k\Omega \cdot cm^2$, while the same configuration in RE displayed 128.5 $k\Omega \cdot cm^2$, indicating higher system resistance in raw effluent likely associated with its lower electrolyte conductivity. Simultaneously, the electrochemical treatment promoted reductions in effluent quality parameters. The initial COD of 4034.77 mg $O_2 \cdot L^{-1}$ decreased to 3868.68 mg $O_2 \cdot L^{-1}$ (StSt-304/Pt RE), corresponding to a 6.6% removal efficiency. Preliminary results indicate the potential for sustainable hydrogen production coupled with effluent remediation. However, further optimizations are required, including electrochemical protocols such as the addition of a supporting electrolyte, surface modification of electrodes, effluent pretreatment, and/or the development of new reactor architectures to mitigate severe passivation effects and enhance economic competitiveness and energy sustainability of the process on an industrial scale.

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