



Full Length Article

Reed pyrolysis system using multi-stage quench scheme for furfural and chemical production: Process analysis and life cycle assessment

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ABSTRACT

This study presents an efficient utilization strategy for reed pyrolysis products, focusing on furfural as the primary product, along with acetic acid, wood vinegar, and phenol-rich oil. Based on this, the Energy-Integration Resource Utilization (EIRU) process, which incorporates a multi-stage quenching method, is developed. This process effectively removes most water from the main organic compounds during condensation by harnessing the internal heat of the high-temperature pyrolysis product stream from the reactor. Compared to conventional pyrolysis process, the EIRU can reduce energy consumption by 50 %. Life cycle assessment reveals that the EIRU process significantly reduces key environmental impact factors, including 90.15 kg CO₂ eq. reduction in Global Warming Potential (GWP), 22.95 kg 1,4-DB eq. reduction in Human Toxicity Potential (HTP), and 1.86 kg Sb eq. reduction in Abiotic Depletion Potential (ADP). Additionally, the EIRU process yields a profit of 151.69 USD/ton, which is 14.81 USD/ton higher than the conventional process. This study highlights the superior environmental and economic performance of the EIRU process, positioning it as a more sustainable and profitable solution for reed pyrolysis.

1. Introduction

Wetlands, often referred to as the “kidneys of the Earth,” provide numerous ecosystem services, significantly contributing to water purification, maintaining ecological balance, and preventing soil erosion [1]. Additionally, wetlands are a significant component of the terrestrial carbon pool in the global carbon cycle [2], serving as important carbon sinks in the biosphere and influencing climate by regulating the carbon cycle in terrestrial ecosystems. Plants in wetlands play a crucial role in water quality purification [3] and also affect the carbon, nitrogen, and phosphorus content in the soil [4]. A study by Xing et al. [3] has shown that wetland plants can significantly reduce nitrogen and phosphorus concentrations in wastewater systems. Xiong et al. [5] studied the

enrichment of metal ions in wetlands by common wetland plants and conducted quantitative analyses. China has the largest wetlands in Asia, accounting for approximately 10 % of the world's wetland area [6].

Reed, a widely distributed wetland plant, is highly effective in removing pollutants [7] and is often described as an ecosystem engineer due to its role in improving the environment [8,9]. However, reed decomposition releases methane, contributing to greenhouse gas emissions. Although reeds can currently be used in various industries such as energy, construction, wood-based panels, and handicrafts, more high-value utilization pathways still need to be explored [10].

Pyrolysis, as an important thermochemical conversion method for biomass, can decompose reeds into combustible gas, biochar, and liquid products (bio-crude) [10,11]. The combustion of the gaseous product

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Article

Life Cycle Assessment of a Cassava-Based Ethanol–Biogas–CHP System: Unlocking Negative Emissions Through WDGS Valorization

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Abstract

To address the high fossil energy dependency and the low-value utilization of stillage (WDGS) in conventional cassava-based ethanol production—factors that increase greenhouse gas emissions and limit overall sustainability—this study develops an integrated ethanol–biogas–CHP system that valorizes stillage and enhances energy recovery. Three process scenarios were designed and evaluated through life cycle assessment (LCA) and techno-economic analysis: Case-I (WDGS dried and sold as animal feed), Case-II (stillage anaerobically digested for biogas used for heat), and Case-III (biogas further utilized in a combined heat and power system). Process simulation was conducted in Aspen Plus V11, while environmental impacts were quantified with the CML 2001 methodology under a cradle-to-gate boundary across six categories, including global warming potential (GWP) and abiotic depletion potential (ADP). Results show that Case-III achieves the highest environmental and economic performance, with a net GWP of $-1515.05 \text{ kg CO}_2\text{-eq/ton}$ ethanol and the greatest profit of 396.80 USD/ton of ethanol, attributed to internal energy self-sufficiency and surplus electricity generation. Sensitivity analysis further confirms Case-III's robustness under variations in transportation distance and electricity demand. Overall, valorizing cassava stillage through biogas–CHP integration significantly improves the sustainability of ethanol production, offering a practical pathway toward low-carbon bioenergy with potential for negative emissions. This study fills a gap in previous life cycle research by jointly assessing WDGS utilization pathways with techno-economic evaluation, providing actionable insights for carbon-neutral bioenergy policies in cassava-producing regions. Certain limitations, such as software version and data accessibility, remain to be addressed in future work.

Keywords: cassava ethanol; life cycle assessment (LCA); wet distillers grains with solubles (WDGS); anaerobic digestion; combined heat and power (CHP); bioenergy system optimization

1. Introduction

As the challenges of global climate change intensify and the “carbon neutrality” goal advances, the pursuit of efficient, clean, and sustainable alternative energy pathways has



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