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Design and Optimization of Multi-State Biogas Reactors: A Step Towards Green Energy Production

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Abstract

As Oman strives to meet its Vision 2040 goals for sustainable development and energy diversification, the need for innovative renewable energy technologies becomes increasingly critical. This research explores the design and optimization of multi-state biogas reactors as a transformative solution to address the dual challenges of waste management and renewable energy production. With municipal solid waste generation in Oman reaching 1.7 million tonnes annually—of which 27% is organic—the potential for utilizing this waste in biogas production through anaerobic digestion remains largely untapped. The study introduces a novel multi-state biogas reactor design capable of operating in single- or two-stage configurations, optimizing methane yield, process stability, and substrate utilization efficiency. Key design elements include advanced mixing techniques, thermal regulation, and microbial immobilization strategies to enhance methanogenesis, the rate-limiting step in biogas production. Experimental investigations focus on the interactions between microbial communities, metabolic pathways, and operating conditions, with feedstocks tailored to Oman's organic waste profile, such as agricultural residues and food waste. A comprehensive techno-economic analysis evaluates the scalability and economic viability of the proposed system for deployment in Oman. The findings aim to provide actionable insights into reducing greenhouse gas emissions, improving energy self-sufficiency, and creating sustainable waste management solutions. By advancing biogas reactor technology, this research aligns with Oman's efforts to transition to a green economy, demonstrating the potential for renewable energy innovations to contribute to national energy security and environmental stewardship.

Keywords
Multi-State Biogas Reactors; Anaerobic Digestion; Renewable Energy; Sustainable Waste Management; Methanogenesis Optimization.