ENHANCING SYNGAS PRODUCTION FROM WASTE THROUGH MICROWAVE-ASSISTED CO-PYROLYSIS OF BIOMASS AND PLASTICS

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Abstract
The increasing global demand for low-emission energy carriers and sustainable waste valorization strategies drives interest in innovative thermochemical processes. In this context, microwave-assisted pyrolysis (MAP) presents a promising route for converting lignocellulosic biomass and non-recyclable plastic waste into high-value gaseous products. This study explores the application of MAP for the co-pyrolysis of selected waste streams to produce hydrogen-rich syngas suitable for downstream chemical synthesis, including methanol, under conditions compliant with the Renewable Energy Directive III. A lab-scale MAP reactor operating at 2.45 GHz was developed using vegetal charcoal as a susceptor to facilitate internal and rapid heating (up to 20 °C/s), achieving process temperatures around 600–700 °C. Feedstocks included low-density polyethylene (LDPE), plastic solid waste, and mixtures with spruce-derived biomass. The experimental results revealed that MAP significantly enhances gas yields and hydrogen selectivity compared to conventional resistive heating. For LDPE, the hydrogen content in the gas phase reached 36.4% by volume, with total gas yields nearly doubling under microwave irradiation. To interpret and optimize the complex thermal dynamics of MAP, a novel dimensionless number “H” was introduced, capturing the relationship between heating rate, feedstock melting, and devolatilization onset. This parameter supports the design and scale-up of microwave reactors by identifying thermal regimes and predicting process behavior under non-isothermal, high-flux conditions. While methanol was not synthesized experimentally, the feasibility of integrating MAP-derived syngas into a methanol production chain was rigorously assessed using UniSim Design® process simulations. The modeled process included syngas compression, conditioning, methanol synthesis in a $Cu/ZnO/Al_2O_3$ fixed-bed reactor, and product purification via distillation. The simulations, based on experimentally measured gas compositions, demonstrated that the methanol production route could achieve greenhouse gas emission reductions exceeding 80% compared to fossil-derived methanol, thus qualifying as a renewable recycled carbon fuel under REDIII guidelines. To support industrial applicability, the design of a continuous MAP reactor was also developed. The unit, capable of processing up to 5 kg/h of PSW under inert conditions, has been engineered to reach a Technology Readiness Level (TRL) of 5, bridging the gap between lab-scale and pilot-scale implementation.