Experimental Investigation of Plastic Waste Catalytic Steam Gasification

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Plastic waste management presents significant environmental and economic challenges, prompting interest in advanced thermochemical conversion technologies. This study investigates the catalytic steam gasification of plastic waste in a bench-scale fluidized bed reactor, focusing on optimizing syngas production and quality while minimizing tar formation. A synthetic plastic waste feedstock was prepared by blending commercial polymers representative of municipal plastic waste compositions. Two experimental conditions were evaluated: a non-catalytic test at a steam-to-plastic ratio of 1.5, and a catalytic test under identical steam-to-plastic ratio using a nickel-based catalyst integrated into a ceramic filter candle, inserted directly in the freeboard of the gasifier, to evaluate the activity of the catalyst in the conversion of tar contained in the real raw-syngas obtained during the gasification process. Under the non-catalytic condition, the system achieved a syngas yield of 2.38 Nm^3/kg with a hydrogen content exceeding 50 vol%, and a lower tar concentration (9.62 g/Nm^3) compared to values typically reported in literature for steam gasification of individual polymers. The observed hydrogen yield, relatively low tar concentration, and low CO_2 levels, attributable to the low intrinsic oxygen content of the feedstock, which favours hydrogen enrichment and limits carbon dioxide formation, demonstrate the effectiveness of the steam gasification process in treating mixed plastic wastes by promoting efficient thermal decomposition and polymer chain reforming. Further improvements were achieved with the integration of a commercial Nickel-based catalyst. The presence of the catalyst led to a 33% increase in syngas yield (3.17 Nm^3/kg) and a hydrogen content exceeding 56 vol%. Total tar concentration was further reduced to 3.37 g/Nm^3, including a 70% reduction in benzene and other polycyclic aromatic hydrocarbons. These results are attributed to enhanced reforming reactions occurring in the catalytic zone, which simultaneously reduced methane, ethane and tar concentrations while improving carbon and water conversion efficiencies. The findings highlight the effectiveness of catalytic steam gasification for plastic waste valorisation, supporting its viability as a pathway for hydrogen-rich syngas production with reduced environmental impacts. The configuration demonstrated here integrates primary gas cleaning and reforming, offering practical advantages for scaling up and integration into circular economy strategies. Future work will focus on catalyst durability, optimization of residence time, and further tar abatement to meet syngas quality standards for downstream chemical synthesis applications.

Keywords: Steam Gasification, Plastic Waste, Fluidized Bed, Hydrogen, Reforming Catalyst.