Pyrolytic Conversion of Waste Biomass towards Alternate and Sustainable Energy

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Abstract

The escalating energy demand and exhausting fossil fuel reserves paving extensive research on alternate energy sources. Moreover, the waste-to-energy concept is a critically compelling approach that can provide a multifaceted solution. Therefore, the present thesis explicates the sustainable pyrolytic conversion of waste biomass to an alternate fuel. Extensive physiochemical characterization was carried out on diverse feedstock ranges for the initial feasibility assessment. The rice stubble was evaluated as the high energy content feedstock with HHV of 15.22 MJ kg^{-1} and 4.76 biofuel reactivity. Subsequently, the severe environmental problem of stubble burning associated with this feedstock facilitated its selection for further investigation. Furthermore, a detailed kinetic, thermodynamic, and reaction pathways assessment was made to get mechanistic insight into the devolatilization process. Differential and integral isoconversional methods were employed to estimate activation energy, pre-exponential factor, and reaction model. In addition, a synergistic analysis of reaction kinetics and heat transfer to model the transport process was reported. The multi-component modelling showed the highest heat transfer with Pyrolysis number of the order 10^{10} for hemicellulose followed by 10^{8} for cellulose and is reduced to 10^{5} for lignin. Subsequently, a fixed bed semi-continuous laboratory scale pyrolysis setup was designed to convert this feedstock into an array of products. Moreover, a comprehensive emission assessment due to the burning of this feedstock was made to quantify the severity of the problem and net environmental gain concerning pollutant reduction. In addition, crucial energy gain analysis was reported in terms of various performance indices. The biochar was evaluated as the most energy valuable pyrolysis product with 0.985 MJ input/ MJ output index and 72.35% energy efficiency. The fossil to energy ratio (*FER*) was 1.28, indicating a net positive energy gain for the system's input resources. Finally, the co-pyrolysis study of this biomass with spent motor oil was investigated to enhance the fuel quality. Moreover, two different modes of operation, namely, in-situ and ex-situ, were implemented to analyze the effect of physical inhibition on the obtained products. A substantial increment of ~85% was observed with 63.12 wt. % bio-oil yield for in-situ operation whilst the only biomass pyrolysis. Furthermore, a significant reduction in the oxygenated groups indicated effective deoxygenation and improved bio-oil stability. Altogether, the present thesis reports a comprehensive investigation, from feedstock selection to pyrolysis product upgradation. Moreover, these results establish the viability of this sustainable waste-to-energy process as an alternative to conventional fossil fuels and encourage its commercial up-scaling.

Keywords: *Waste-to-Energy; Pyrolysis; Biofuel; Devolatilization kinetics; Thermodynamics; Heat transfer; Stubble burning; Emission Inventory; Net energy balance; Co-pyrolysis*