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Biomass waste to Energy: Investigating syngas production from pyro-gasification of sawdust blends of Invasive Alien Plants and Tropical tree species

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ABSTRACT

Conventional biomass gasification is associated with technical issues which limit its scale-up to full commercialization. These issues include but are not limited to high tar composition in the syngas produced, low syngas yield, and expensive and inefficient tar cleaning procedures. Biomass pyro-gasification can be defined as a hybrid or multi-stage integration of pyrolysis and gasification process, controlled independently to separate and restrict tar from being gasified alongside char. This is capable of producing high yields of syngas with less tar impurities suitable for downstream applications.

By employing pyro-gasification, this research aimed to investigate the properties of syngas contained in the product gas, produced from the thermochemical conversion of wood wastes. These enormous wood wastes samples were sourced from different Invasive Alien Plants (IAPs) and commercial sawmill tropical woods. Firstly, the individual samples were subjected to a series of characterisations to ascertain their fuel properties and suitability for pyro-gasification. These tests include their structural composition, proximate and elemental composition, char yield, char reactivity, higher heating value (HHV), bulk density, fuel ratio, and energy density. A fuel quality evaluation of the samples was conducted to rank the samples accordingly. This was used to gain better understanding of the behaviour of each sample when subjected to pyro-gasification. Furthermore, the samples were subjected to a thermogravimetric analysis to ascertain their rates of volatilization, char decomposition, and maximum decomposition temperatures. Based on their thermogravimetric analysis and differential thermogravimetry, a kinetic study was conducted to inform the viability of the samples and the selection of suitable operating parameters for optimum process efficiency.

Finally, in conducting the pyro-gasification experiment, the sawdust sizes of the wood waste samples were first pyro-gasified individually (i.e. 100 % wt. of the feedstock). Subsequently, the samples were blended with each other in three separate mix ratios – 30/70 (i.e. 30 % wt., and 70 % wt. of 20 g of the feedstock), 50/50 and 70/30. The product gas produced from each experimental run was

sampled at 900°C, 950°C, and 1000°C, and analysed using a TCD Gas Chromatograph (GC). The properties of the syngas (and those of its component gases CO and H_2) determined are the – percentage concentration in the product gas, syngas yield per gram of biomass feedstock, volumetric flow rate, rate of production of the gas and the physical properties of the flame generated when the syngas was ignited.

According to the data collated, syngas concentrations in the product gas were generally high across the board, averaging 96.4%. Meanwhile, trace concentrations of CH_4 and CO_2 were observed in the product gas. The ratio of H_2/CO in the syngas averaged 0.06 at 900°C and was observed to increase to averages of 0.16 and 0.46 with increase in temperature to 950°C and 1000°C respectively. The production rate of the syngas and those of its gaseous components – H_2 and CO, were also affected by the increase in temperature. The most significant increases in the gas production rate were observed with the H_2 as the temperature was increased from 900°C to 1000°C. In general, the IAPs showed the highest increases in H_2 production rate, attaining significant increases with the rise in temperature from 900°C to 1000°C. The 100% wt. of the Poplar feedstock, in particular, exhibited a significant increase in H_2 production rate from 130.12 mL/min/gram at 900°C to 3556.14 mL/min/gram at 1000°C. Meanwhile, the highest hydrogen production rate of 7937.07 mL/min/gram attained across the board was exhibited by the Eucalyptus-Jacaranda 30/70 blend. Most IAP blended samples exhibited higher syngas production rate than their associated individual samples at a lower temperature of 900°C. However, with an increase in temperature to 1000°C, the syngas production rate from most of these blended samples declined significantly.

The syngas yields (i.e. the volume of syngas produced from a gram of wood feedstock), from most samples were significantly high, particularly at 900°C. These yields were subsequently increased at 1000°C. The highest syngas yield of 744.42 mL/gram was obtainable from the Eucalyptus-Bugweed 30/70 blend, while the lowest yield of 518.05 mL/gram was obtainable from the Jacaranda-Poplar 30/70

amongst all IAP samples and their blends. Meanwhile, among the tropical samples and their blends, the highest syngas yield of 735.8 mL/gram of feedstock was obtainable from the Mahogany-Opepe 30/70 blend, while the lowest yield of 493.7 mL/gram of feedstock was obtainable from the African mahogany-Opepe 70/30 blend. These were generally higher than those obtained from the 100% wt. of the individual tropical wood samples.

This thesis has been carefully documented to (a) prove the viability of pyro-gasification as a tar removal process for syngas production at reduced gasification temperatures; (b) showcase the viability of wood wastes of invasive alien plants and commercial tropical trees which are yet to be explored for syngas production and; (c) showcase the possibility of optimizing syngas production by blending two wood species in different mix ratios. Some of the findings on results of the characterization of the samples, their thermogravimetric analyses, as well as data on their syngas production via pyro-gasification as described in chapters four, five and six respectively, have either been communicated as scientific articles in journals, presented in conferences or have been submitted and awaiting publication (see Appendix C for this list).