ABSTRACT

This study looked at the possibility of using hydrothermal carbonization (HTC) to produce densified solid biofuel from the organic fraction of municipal solid waste (food and yard waste). The impact of various severities of hydrothermal carbonization of the yard and food waste on the structural, physicochemical, and combustion properties of hydrochar produced was investigated. The hydrochar produced was then pelletized into biofuel pellets and its properties like; fuel, mechanical, storability, and transportability were also investigated in this study. A strategy for the reusability and valorization of wastewater (process waste) generated during Co-HTC conditions was also established. This study also included the techno-economic and environmental footprints involved with the treatment process, as well as framework creation and policy suggestions. The thesis findings revealed that an energy-rich hydrochar could be produced that outperforms its precursor in terms of physiochemical and fuel properties. The study's findings revealed that the HTC of the organic component of municipal solid waste, such as yard waste, provides an opportunity to generate energy-dense solid fuel (hydrochar) with a calorific value of up to 24.6 - 27 MJ/kg, equivalent to lignite coal. As severity increases, the hydrochar yield declines while its fuel properties improve. Decarboxylation and dehydration allow functional groups to become impaired, including C–O and –OH. The grindability of the prepared hydrochar was comparable to that of coal. Hydrochar produced at lower reaction condition (160–200 °C at 2 h) have better flowability as compared to that produced at higher reaction condition (4–24 h at 200 °C). Yard waste hydrochar was suitable for fluidized bed combustion when produced at a lower reaction condition. Hydrochar prepared at a higher reaction condition on the other hand was better suited to making briquettes and fuel pellets. Hydrochar has the advantages of grindability, hydrophobicity, and energy density over raw feedstock making it a superior fuel. The higher quality of yard waste hydrochar also improves the storage and transportation of the fuel pellets produced. When compared to yard waste hydrochar pellets produced at low severity, higher HTC severity creates brittle yet durable pellets. Food waste (FW) on the other hand gets easily carbonized as evident from low hydrochar yield since, the carbonization potential of food waste is directly proportional to its severity. The increased severity also encourages the development of carbon microspheres. The requirement for a binder was realized during the pelletization of food waste hydrochar. The lack of solid bridge formation between the food waste hydrochar particles resulted in the pellets with low

tensile strength. The energy density and strength of the FW hydrochar pellets produced increased when molasses was used as a binder. Pellets containing 30% molasses as a binder had the maximum mass density (1683 kg/m^3) and the highest energy density (37.54 GJ/m^3). Molasses recrystallization aids in the production of strong hydrochar pellets by acting as a binder. Furthermore, the FW hydrochar has high-oxygenated functional groups on its surface, which was evident from FTIR results. These functional groups operate as a nucleophilic site for the electrophilic sites of molasses saccharide functionality. These chemical interactions between hydrochar and molasses aid in the formation of chemical bridges with the hydrochar particles which enhances overall pellet matrix binding ability and durability. However, molasses, on the other hand, which is used as a binder in food waste hydrochar pellets, has a proclivity for absorbing moisture. The need for commercial binders is reduced by co-hydrothermal carbonization of non-lignocellulosic food waste and lignocellulosic yard waste. The lignin concentration in yard waste hydrochar was increased by hydrothermal carbonization and softened during heated pelletization (90^{o}C) which served as a natural binder. Soften lignin of yard waste hydrochar when pressed engulfs the food waste hydrochar particles when pelletized together. The softened lignin solidifies when the pellets cool thus providing a solid bridge within the pellet matrix. Using anaerobic digestion and recirculation, a reusability and valorization approach for wastewater (process water) generated during Co-HTC conditions was developed which lowered the upstream and downstream water and wastewater-related burden. The anaerobic biodegradability of the process water generated during Co-HTC was 72% of which the experimental and theoretical methane yields was 224 mL/g COD and 308 mL/g COD, respectively. The presence of high organic and ionic species in recirculated process water aided the overall carbonization process which was evident from the enhanced energy yield (86–92%), carbon content (68–71%), and calorific value (20–27 MJ/kg).

Given the current low market value of hydrochar, economic analysis suggested that the significant capital cost required due to plant complexity, the commercial application of the technology may be not feasible at this time and cost incurred may not be offset by the additional revenues generated. Nonetheless, overall economic potential of HTC could be boosted by economies of scale and as well as by an increase in hydrochar output and its use as a renewable fuel. According to the life cycle assessment study, the HTC reactor contributes to environmental pollutants in all impact categories. In terms of climate change, the HTC reactor is responsible for around 75%

of total emissions. The coal-based energy mix is the primary source of emissions. According to the sensitivity study, switching to Germany's energy mix (which includes 18% coal) could lower overall emissions by 63 %. Even though the technology is still in its early phases of development, with knowledge gaps and flaws, research conducted indicated that HTC has the potential to become a future technology. The techno-economic and LCA assessments both emphasized the need for more research to address the present flaws of the technology and to also develop a revenue-generating business model.

Keywords: Hydrothermal carbonization; Yard waste; Food waste; Biofuel; Fuel pellets; Life cycle assessment; Techno-economic assessment; Organic fraction of municipal solid waste.