Hydrothermal liquefaction of swine manure and food waste: a pathway to sustainable energy and soil improvement

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Keywords: swine manure, food waste, hydrothermal liquefaction
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Sustainable solid waste management represents a critical challenge in our society. The agricultural and livestock industries are a major source of waste generation. Among them, swine manure (SM) and food waste (FW) stand out for their high organic content and valorization potential (Lu et al., 2018). Traditional disposal methods, such as land application or incineration, led to greenhouse gas emissions, water pollution, and soil degradation, highlighting the need for alternative waste treatment focused on material and energy recovery. Hydrothermal liquefaction (HTL) has emerged as a promising thermochemical technology for converting wet biomass into bio-oil, characterized by a high energy content and suitability for conversion into renewable fuels, positioning HTL as a feasible solution for sustainable energy production (Ebrahim et al., 2025; Pecchi et al., 2023). In addition to bio-oil production, some valuable products are obtained, such as a carbonaceous material (hydrochar) and an aqueous phase (process water), rich in nutrients and organic compounds.

This study aims to assess the impact of key process variables, such as temperature and reaction time, on the efficiency and products distribution of HTL enhancing bio-oil yield. Moreover, hydrochar and process water are also characterized to establish a potential application of each subproduct. These findings underscore the potential of HTL as an integral component of sustainable waste management strategies, aligning waste valorization with renewable energy goals.

Swine manure, provided by a pig farm (Ávila, Spain), showed a moisture, carbon and ash content of 70%, 46% and 13%, respectively, and was used as received. Food waste, primarily composed of fruits, vegetables, and leafy greens, exhibited a moisture, carbon and ash content of 92%, 42% 6%, respectively. The FW was ground, homogenized, and frozen prior to use. HTL experiments were carried out in a 1.8 L high-pressure PARR reactor (4570, PARR Instrument Company, USA) with a feedstock loading of 800 g, corresponding to 9% dry weight for SM and 5% for FW. The reactions were carried out between 270 and 330 °C for 60 min under autogenous pressure. At the highest temperature (330 °C), reaction times were additionally varied to 15 min – 60 min. Bio-oil and hydrochar were analyzed for elemental composition (C, H, N, S), proximal analysis (ASTM D3173-11, D3174-11, and D3175-11), mineral elements and heavy metals. The higher heating value (HHV) of both bio-oil and hydrochar was calculated on a dry basis from their elemental composition (C, H, N, S) and ash content. The textural properties of hydrochar derived from both SM and FW were characterized by CO_2 adsorption isotherms. Process water was characterized by pH, conductivity, total organic carbon (TOC), total nitrogen (TN) content, total solids (TS), and volatile solids (VS). The bio-oil was characterized in detail by gas chromatography-mass spectrometry (GC-MS) to identify and quantify individual compounds, particularly those with potential for chemical products or fuels. The potential of the process water for nutrient recovery by precipitation of P-rich salts or its suitability for biogas production by anaerobic digestion was also evaluated.

The HTL of SM and FW resulted in the production of hydrochar, PW, bio-oil, and a gas fraction. Figure 1a shows the yield of each fraction on a dry basis at the different liquefaction temperatures. A gradual increase in bio-oil yield was observed for both feedstocks with the temperature. While in the case of bio-oil produced from SM, the yield ranges between 11% and 17%, when produced from FW yields higher than 20% were reached. The production of hydrochar from SM decreased with temperature between 55% and 33%. No significant changes were observed in the hydrochar yield from FW (≈ 25%). The contribution of process water to the product distribution was much lower in the case of SM than FW, and its yield decreased with the temperature. The gas fraction contributes 25-45% of total mass for SM and 28-36% for FW.

Figure 1b shows the yield of each fraction at 330 ºC at several reaction times. For SM, the hydrochar yield decreased with increasing reaction time (from 63% to 33%) causing an increase in the gas fraction, while the bio-oil and process water yields remained unchanged. In the case of FW, bio-oil yield showed a clear dependency on reaction time, slightly increasing (from 19% to 25%), while the yield in hydrochar and process water decreased.

The bio-oils obtained from both feedstocks exhibited HHV above 33 MJ/kg. The characterization of hydrochars revealed its potential use as solid fuel according to ISO 17225-8:2024. The hydrochar obtained from SM showed a carbon, nitrogen and sulfur content of 57%, 2.5%, and 0.7%, respectively. The VM was less than 55% and the ash content reached 23%. The HHV increased from 23 MJ/kg for SM to 25 MJ/kg for the hydrochar. In the case of FW, a better hydrochar was obtained, with an HHV of 36 MJ/kg. All the hydrochars fulfill the standards for sustainable soil nutrition and maximum allowable limits for heavy metals to be used as organic soil amendment regarding Spanish regulations (Royal

Decrees 1051/2022 and 824/2024). The hydrochars retained relatively high amount of nutrients, including phosphorus (2–27 g/kg), potassium (1–15 g/kg), and calcium (7–35 g/kg). In addition to fulfilling these thresholds for metals, the nutrient composition further supports the suitability of hydrochars as a soil amendment, enabling nutrient recycling while minimizing environmental risks.

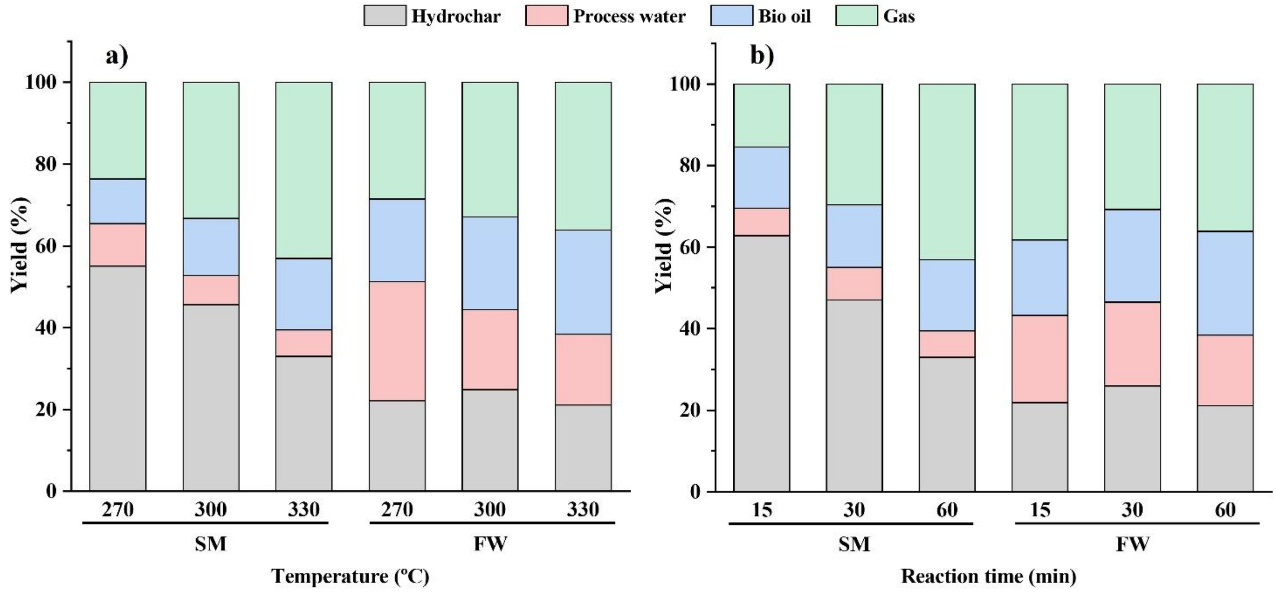

Figure 1. Product distribution of HTL treatment of SM and FW: (a) 270-330 ºC at 60 min, (b) 15-60 min at 330 ºC.

Process water from HTL of SM and FW were characterized by an acidic pH (≈ 4.5) and a conductivity ranging from 6 to 6.5 mS/cm. The TOC concentration was high in all the cases, increasing with the HTL temperature (7 – 17 g/L). Although there were differences in the process water composition depending on the waste treated, both could be managed by anaerobic treatment to transform the organic matter into biogas and obtain an effluent that could be recirculated to the process, reducing the negative environmental impact associated with these liquid effluents.

HTL proved to be a versatile and sustainable technology for the management of agricultural and livestock waste, contributing to the objectives of circular economy and renewable energy production. The treatment yields an energy-dense bio-oil, a hydrochar with potential as a soil amendment or solid biofuel, and a process water rich in organic matter. Future work should explore optimizing conditions for specific applications of HTL products.

Acknowledgements

Authors greatly appreciate funding from Spanish MCIN/AEI/10.13039/501100011033 and European Union “NextGenerationEU/PRTR” (TED2021-130287B-I00 and PID2022-138632OB-I00). B. Chiguano-Tapia acknowledges research scholarship PREP2022-000792.

References

Ebrahim, S. A., Jiang, X., Kodra, O., Couillard, M., Baranova, E. A., & Singh, D. (2025). Insights into the effect of various supports on hydrothermal liquefaction of food waste over iron-oxide nano-catalysts. *Applied Energy*, *378*. https://doi.org/10.1016/j.apenergy.2024.124808

Lu, J., Watson, J., Zeng, J., Li, H., Zhu, Z., Wang, M., Zhang, Y., & Liu, Z. (2018). Biocrude production and heavy metal migration during hydrothermal liquefaction of swine manure. *Process Safety and Environmental Protection*, *115*, 108–115. https://doi.org/10.1016/j.psep.2017.11.001

Pecchi, M., Baratieri, M., Maag, A. R., & Goldfarb, J. L. (2023). Uncovering the transition between hydrothermal carbonization and liquefaction via secondary char extraction: A case study using food waste. *Waste Management*, *168*, 281–289. https://doi.org/10.1016/j.wasman.2023.06.009