The Role of Process Intensification on Hydrothermal Technologies: Applications at the BioFairNet Pilot Site

Dimitrios Liakos, Stergios Vakalis*
University of the Agean, Department of Environment, Mytilini, Greece
Presenting author: vakalis@aegean.gr
*Corresponding author: vakalis@aegean.gr

- **Introduction of HYDROPYR; A novel coupling of HTC and pyrolysis pilot system with PI enhancements.**
- **Preliminary experimental results show hydrochar mass yields of 40-50% and HHVs of 20 – 25 MJ/kg.**
- **Real-time data acquisition via SCADA will be applied for gas monitoring and process optimization**
- **The study has the scope to highlight the incorporation of PI applications in HYDROPYR and and discuss the potential and the limitations.**

Introduction

Hydrothermal technologies encompass a suite of thermochemical processes that utilize high-temperature, high-pressure water environments to convert wet biomass into valuable bio-based products. Among these, hydrothermal carbonization (HTC), stands out as a promising method for processing high-moisture feedstocks without requiring prior drying. HTC typically operates at temperatures ranging from 180°C to 300°C under self-generated pressures, facilitating the conversion of organic matter into hydrochar, a carbon-rich solid (1). This process emulates natural coalification but occurs over hours rather than millennia, enhancing both energy efficiency and resource recovery. HTC is recognized for its potential in producing biofuels, soil amendments, and chemical feedstocks while reducing greenhouse gas emissions. Furthermore, the exothermic nature of HTC improves process sustainability by minimizing external energy inputs, making it particularly advantageous for circular bioeconomy applications. Despite these benefits, the ecotoxicological impact of hydrochar warrants careful evaluation. Studies have highlighted that hydrochar may contain phytotoxic organic compounds which could pose risks to plant growth and soil microbial communities.

The low quality hydrochar can be enhanced by coupling HTC with pyrolysis in a novel concept that is intoduced here and is neamed HYDROPYR (2). Nonetheless, regulating the energy demand, reducing the emissions and the overall efficiency of the process remainns a challenge. Process Intensification (PI) provides transformative potential for hydrothermal technologies, significantly enhancing efficiency, sustainability, and economic viability. This innovative approach not only reduces resource consumption but also maximizes product yield and quality by integrating advanced analytical techniques and process optimization strategies (3, 4). The BioFairNet project, funded by Horizon Europe, demonstrates these advancements through its Pilot Site 1, where a coupled HTC-pyrolysis reactor system efficiently converts agro-waste into high-value bioproducts, including biochar and bio-oil. The integration of a 3 KW photovoltaic (PV) system ensures a sustainable energy supply, enabling off-grid operations and significantly reducing greenhouse gas (GHG) emissions, aligning with the project's objectives of promoting circular economy practices and carbon neutrality.

Methods

The feedstock potential is assessed through physicochemical analysis, including pH, moisture content, calorific value, alongside COD and total phenolic content measurements (5). Gas chromatographic analysis, using a Shimadzu Nexis 2030 GC with HP-FFAP and MEGA 10 columns, is employed for the quantification of volatile organic compounds (VOCs), volatile fatty acids (VFAs), and fatty acid methyl esters (FAMEs).

The methodologies for the analysis of the HYDROPYR pilot plant are designed to optimize hydrothermal by integrating process intensification principles, real-time monitoring, and advanced analytical techniques. The pilot infrastructure includes a high-pressure HTC reactor (200–350°C, 20–60 bar), integrated with solar PV panels for sustainable operation, and a pyrolysis system for enhanced carbonization. Real-time data acquisition via SCADA ensures operational efficiency, tracking CO2 emissions and conducting in-situ gas quality assessments.

Results and discussion

Preliminary numerical results from hydrothermal experiments underscore the system's potential. Hydrothermal treatment experiments demonstrated significant variations in hydrochar mass yield, calorific value, and liquid product composition based on process conditions. Hydrochar yields excedded 50% for HTC of anaerobic sludhe decreased with increasing temperature, from 46% at 280°C to below 35% at 300°C. The higher heating value (HHV) of hydrochar remained high, reaching 28.05 MJ/kg for wine sludge hydrochar and 26.55 MJ/kg for olive mill wastewater-derived hydrochar. Volatile fatty acids (VFAs) such as formic, acetic, propionic, butyric, and isovaleric acids were present, with hydrochar addition promoting medium-chain VFAs like isocaproic and caproic acids. A total of 400 mg/L of combined VFAs was measured for most of the experiments. Chemical oxygen demand (COD) levels fluctuated, was measured to be higher than 12,500 mg/L at temperatures lower than 280°C, dropping below 8,000 mg/L at 300°C. SimilarlyTotal phenolic content (TPC) was highest at 2689 mg/L at 280°C, decreasing to 869 mg/L at 310°C, with a minor increase at 325°C. The pH of hydrothermal liquid varied widely, ranging from 3 to 11, with lower pH values correlating with increased organic acid production at elevated temperature

Conclusions

This study will present the preliminary experimental results and has the scope to highlight and discuss the potential and the limitations of HTC technologies to incorporate PI applications. This integrated system aims to offer a replicable model for addressing waste challenges while supporting resource recovery. By integrating renewable energy, real-time monitoring, and advanced analytical techniques, the BioFairNet pilot site serves as a replicable model for waste valorization, demonstrating the potential of hydrothermal technologies in creating sustainable bio-based economies while significantly reducing environmental impact and enhancing resource efficiency.

References

1. Liakos, D., Altiparmaki, G., Moustakas, K., Malamis, S., Stergios Vakalis, S. (2024). The fate of Volatile Fatty Acids (VFAs) during the thermodynamic transition from hydrothermal carbonization to hydrothermal liquefaction: HtC-to-HtL, Sustainable Chemistry and Pharmacy 41, 101683.
2. Karatas, O., Khataee, A. and Kalderis, D. (2022) 'Recent progress on the phytotoxic effects of hydrochars and toxicity reduction approaches', Chemosphere, 298, p. 134357.
3. Rissanen, J. V. et al. (2022). Intensification of Hydrothermal Biomass Fractionation with the Help of Oxygen: Kinetics and Modeling. ACS Sustainable Chemistry & Engineering, 10, 12808–12816..
4. Haase, S., Tolvanen, P., Russo, V. (2022). Process Intensification in Chemical Reaction Engineering. Processes, 10, 99.
5. Zhu, K. et al. (2021). Valorization of Hydrothermal Carbonization Products by Anaerobic Digestion: Inhibitor Identification, Biomethanization Potential and Process Intensification. Bioresource Technology, 341, 125752.