Hydrothermal liquefaction of agri-food waste: Concentrated solar thermal coupling with a sensible heat storage system

N.I. Tsongidis[1], C.A. Poravou[1], C. Lekkos[1], G. Karagiannakis[1], B. Ulkutasir[2,3], D. Baker[2,3],
O. Taylan[2,3]

[1]ARTEMIS Lab, Centre for Research & Technology Hellas (CERTH), Thermi, Thessaloniki, 57001, Greece [2]Center for Solar Energy Research and Applications (ODTÜ-GÜNAM), Çankaya, Ankara, 06800, Türkiye [3]Middle East Technical University (METU), Çankaya, Ankara, 06800, Türkiye

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Presenting author email: ntsongid@certh.gr

The impending depletion of fossil fuels and their role in exacerbating the greenhouse effect necessitates the investigation of alternative sources for biofuel production (Akhtar *et al.*, 2011). Agricultural waste constitutes a substantial energy reservoir and holds promise as a renewable fuel feedstock, especially in areas with high agricultural activity (Deniel *et al.*, 2016). However, in most of the relative processes, an energy-intensive drying step is required before their treatment. Hydrothermal liquefaction (HTL) presents a thermochemical approach for converting residual biomass into fuel-like substances in the area of sub- or supercritical water conditions (250-550°C, 5-25 MPa). In this process, water serves as both a reactant and a solvent (Elliott *et al.*, 2013). Products comprise biocrude, which is a viscous oil, an aqueous phase containing inorganic matter (mainly phosphates and nitrates), a gaseous phase, and, depending on the feedstock and the applied conditions, solid bio-char. The resulting biocrude can undergo further enhancement through catalyst addition or hydrotreatment to achieve properties akin to liquid hydrocarbons. At the same time, the abovementioned byproducts can be utilized in several different applications, including fertilizers and soil fermenters. Solar-assisted HTL can prove to be a cost-effective and energy-efficient method by combining HTL with Concentrated Solar Technologies (CST) to supply the requisite heat. Additionally, due to the intermittent nature of solar energy, the integration of a thermal energy storage (TES) system is deemed necessary, prolonging the operational window of the process.

The current study was based on agri-food waste that was used as feedstock, including shredded peach stones and peach skins under experimental temperatures that ranged from 250 to 350°C, two initial pressures (1, 20 bar) and a steady retention time of 30 min, while the purge gas was N_2. Biocrude yield was calculated using the equation of Chen *et al.* (2014), where biocrude yield is based on the ratio of pure biocrude mass over the dry feedstock mass. The Higher Heating Value (HHV) and elemental composition (C, H, N) were determined to ascertain characteristic physicochemical attributes of both feedstock and biocrude, while the moisture content was measured via thermogravimetric analysis (TGA). Lastly, the gaseous phase was analyzed using Gas Chromatography (GC).

The experiments first took place in a 1.8L, electrically heated autoclave reactor (Tsongidis *et al.*, 2020), followed by verification experiments in an in-house solar simulator (Poravou *et al.*, 2022) representing close-to-realistic conditions for the solar HTL process (Figure 1a, 1b). The solar simulator consists of 4 Xenon arc lamps, while the artificial solar irradiation fluxes through an 80 mm cavity aperture and is eventually concentrated on the autoclave reactor-receiver.

A mobile platform (Figure 1c, 1d) consisting of two modular, semi-continuous reactors with a total capacity of 12 L was constructed and preliminarily evaluated. The reactors are heated via parabolic trough collectors (PTC).

The following Table 1 summarizes the physicochemical characterization of the feedstocks, while the same analysis will be provided for selected tests, including the biocrude yield and the comparison of the efficiency of electrical and artificial sunlight heating, respectively.

a)

b)

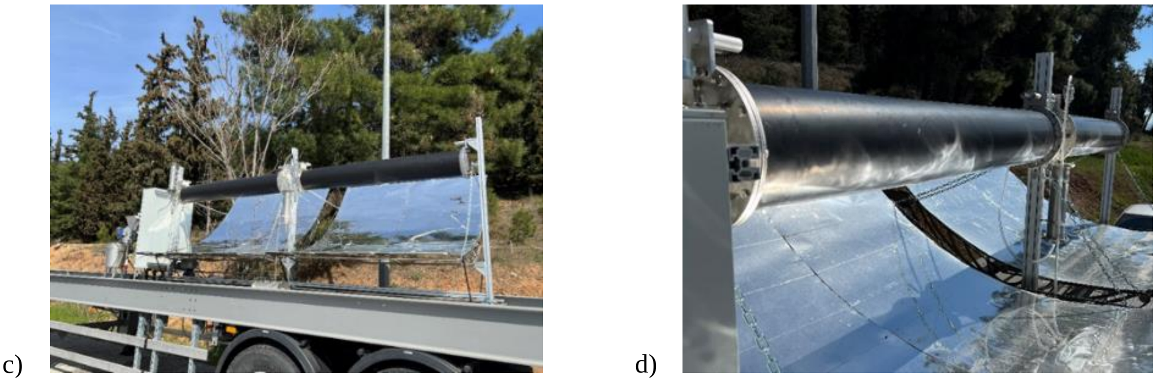

Figure 1. a) HTL reactor and in-house solar simulator setup; b) Solar simulator integrated HTL reactor during operation; c), d) Pilot-scale mobile HTL reactor with parabolic troughs

Table 1. Physicochemical characterization of different feedstocks

Feedstock	HHV (MJ/kg)	C %	H %	N %	H/C	Moisture (%)	Inorganic impurities	Toxic compounds
Peach stones	6.3	47.70	6.31	1.53	0.13	1.91	Negligible	No
Peach skins	18.7	46.90	6.29	0.64	0.13	65.63	Negligible	No

In the novel conceptual scheme, a TES system will be coupled to the HTL reactor to provide heat during the off-sun hours (Figure 2). The TES system will be based on cost-efficient and abundant ceramic materials. The system will be designed numerically and sized for optimum performance, and the numerical model will be validated by an experimental campaign. In the schematic, the red arrow indicates the operating conditions of the heat transfer fluid (HTF) cycle for charging TES, while the blue arrow represents the conditions where the reactor is under low or no solar intensity and requires heating supplied by TES, i.e., discharging TES.

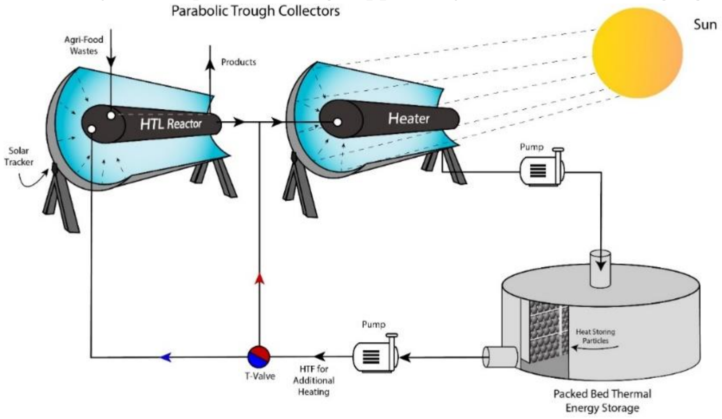

Figure 2. Representative sketch of the combined system of HTL reactor supported with parabolic trough collectors and thermal energy storage

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