

# Process intensification of lignocellulosic biomass liquefaction: transitioning from batch to continuous supercritical water systems for biofuel precursors production

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## Highlights

- An updated Severity factor (R0) was employed to scale-up HTL of lignocellulosic biomass from batch to continuous reactors.
- Process intensification was achieved, reducing reaction time from hours to seconds.
- The continuous processing of wood using supercritical water tends more to the liquefaction of the wood material, instead of the carbonization in batch.

## 1. Introduction

Mitigating carbon emissions is essential to minimize environmental impact and decelerate climate change. Decarbonizing aviation remains a critical challenge, as conventional sustainable alternatives often prove inadequate for the sector's operational demands. Sustainable Aviation Fuels (SAF) derived from lignocellulosic biomass offer a promising solution. Among the available technologies, hydrothermal liquefaction (HTL) stands out as a leading thermochemical pathway, utilizing sub- or supercritical water to convert biomass into biofuel precursors. However, most fundamental studies remain limited to batch systems [1-3]. In fact, transitioning from traditional batch systems to continuous supercritical water (SCW) systems represents a significant leap in Process Intensification (PI). This work addresses the technical challenge of scaling up the HTL of pine by utilizing an updated Severity Factor (R0) as a "translator" between scales, achieving a dramatic reduction in residence time of two to three orders of magnitude—from 15–60 minutes in batch to 1–20 seconds in continuous mode.

## 2. Methods

A preliminary screening evaluating the temperature (150–350 °C), reaction time (0-90 minutes) and pH (acid, natural or basic) was performed in a batch reactor to determine the optimal conditions of the transformation of pine wood into bio-oil, the biofuel precursor, attending to its composition and carbon content. The products were separated into different phases, these being aqueous, char and bio-oil phase, and each one was analyzed to determine its composition. The mass balance of the process was also determined, focusing on carbon and its distribution among the different phases.

These conditions were then successfully replicated and intensified in the "Pressurized Hydrolysis Unit 2" (PHUn2). This unit features a unique Sudden Expansion Reactor (SER) designed to exploit the vanishing surface tension and low viscosity of supercritical water. This configuration enables near-instantaneous quenching, effectively "freezing" the reaction intermediates and preventing the secondary condensation and repolymerization reactions that lead to hydrochar formation in slower batch systems. Subcritical (330-340°C, 240 bar) and supercritical conditions (375–385 °C, 250 bar) were evaluated and the products were separated and analyzed as they were during batch screening to enable the comparison between both processes.

## 3. Results and discussion

Initial batch optimization established a benchmark bio-oil carbon yield of ~40% at 250 °C (R0≈40–80 min). This range of conditions was replicated in the continuous system, and the comparative analysis between the subcritical batch and supercritical continuous modes revealed a fundamental shift in carbon distribution. While bio-oil yields remained stable (~40%), the continuous SCW process significantly enhanced the aqueous phase yield (reaching 40–80%) while effectively minimizing solid residue (char). GC-MS and simulated distillation of the bio-oil confirmed that despite the drastically shorter residence times and the shift in reaction pathways, the chemical quality of the bio-oil remained remarkably consistent across both scales.

#### **4. Conclusions**

The tailored severity factor developed in this work facilitated an effective transition from batch-scale to continuous-flow processing. Specifically, in the HTL of wood, process intensification was achieved, effectively shortening reaction time from hours to seconds in the continuous reactor. Ultimately, these findings establish that continuous supercritical processing, which minimizes the solid residue, provides a viable and efficient framework for the industrial-scale valorization of lignocellulosic biomass.

#### **References**

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#### **Keywords**

Hydrothermal liquefaction, supercritical water, continuous reactor, severity factor.