Development of a laser-heated facility to investigate coking in ablators

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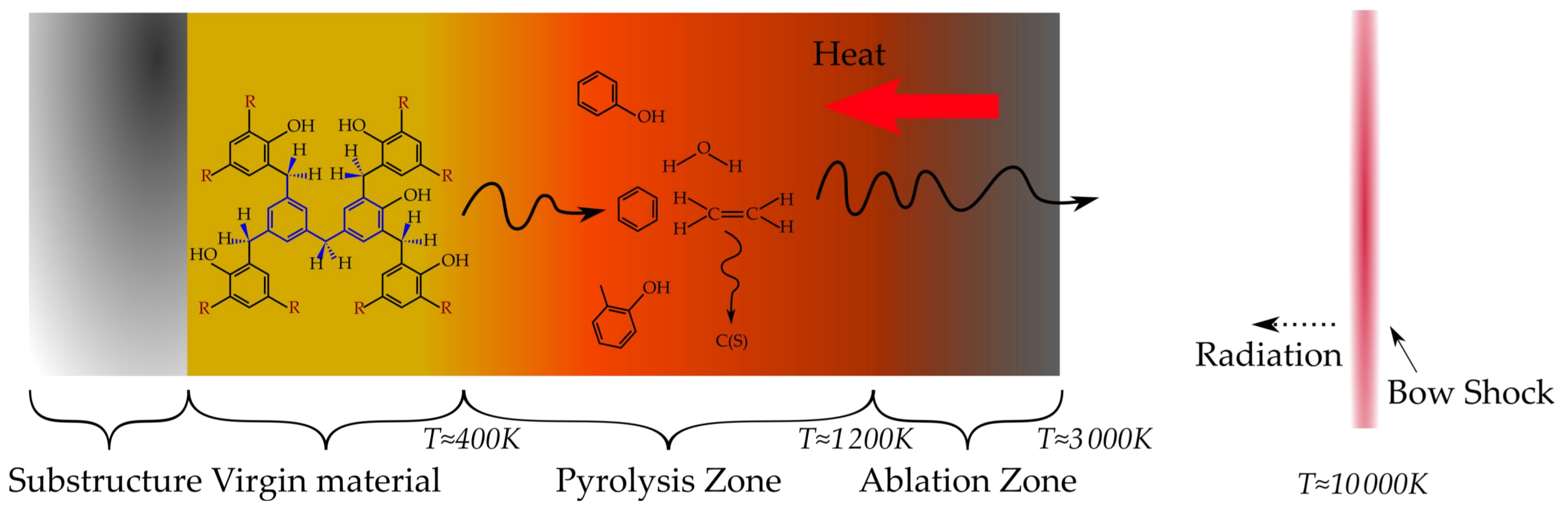
Overview

This work introduces a novel experimental setup to investigate carbon deposition during pyrolysis in carbon/phenolic ablators. A high-power laser heats fibrous materials while pyrolysis-relevant gases are injected, with real-time monitoring of test conditions. Post-test SEM and micro-CT analyses support the development of chemical models for heterogeneous reactions in porous media, relevant to thermal protection systems.

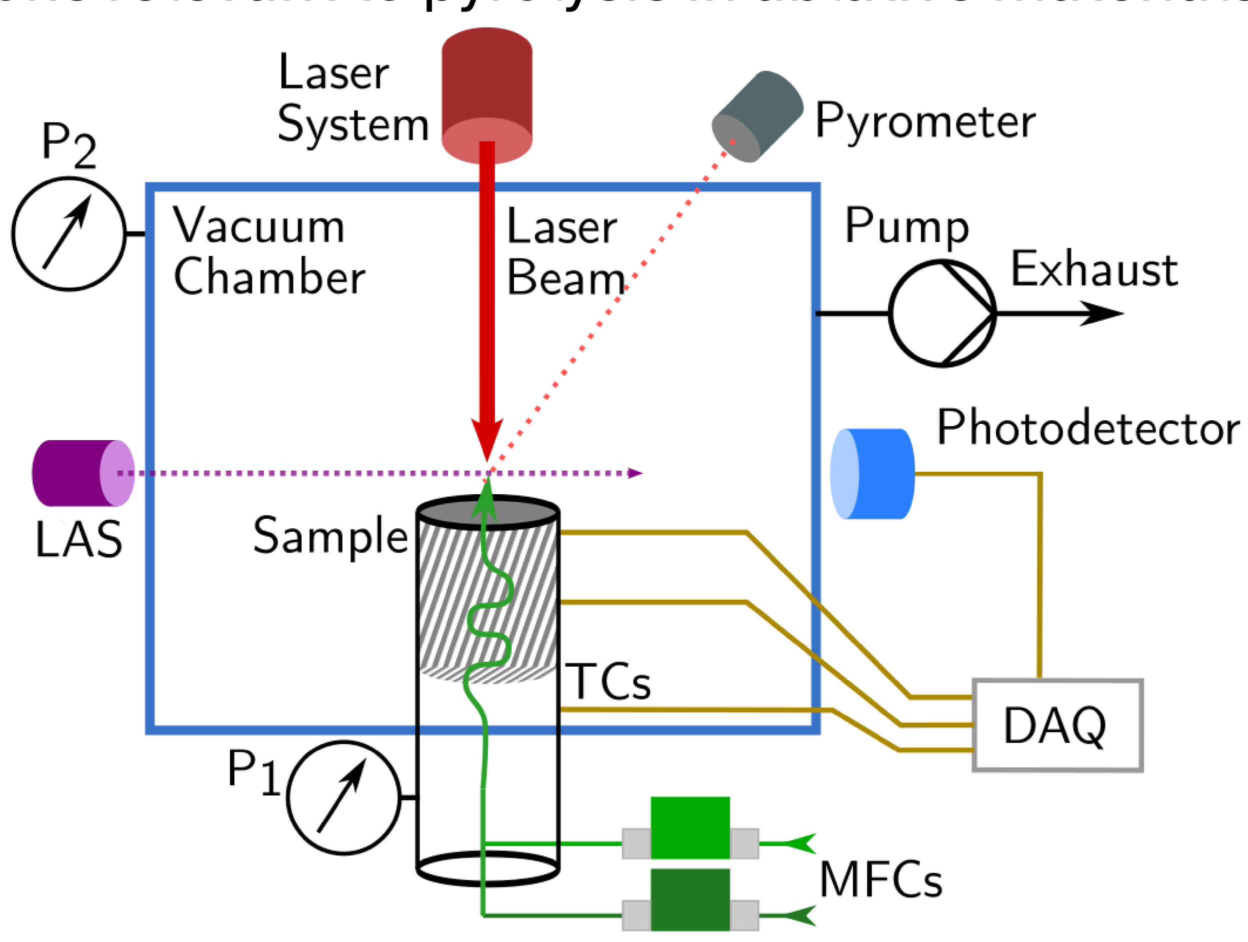
Introduction

As the phenolic resin pyrolyzes and migrates through the fiber preform, it encounters extreme temperatures that drive both homogeneous and heterogeneous reactions. These processes can lead to carbon deposition on the fibers, altering properties such as density, permeability, and thermal conductivity. They also modify the gas flux composition at the surface, directly impacting the boundary conditions used in ablation modeling.

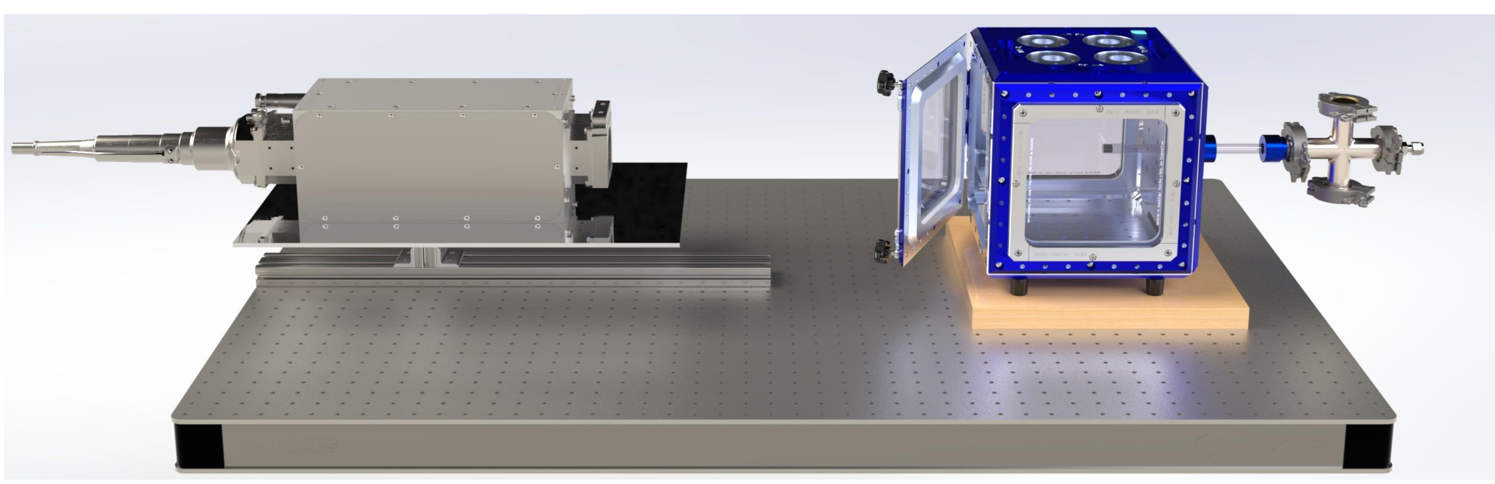


Facility development

To replicate these processes in a controlled setting, we are developing a facility that injects gases from the base of the sample while a 1.5 kW laser heats the top surface. The setup includes pressure measurements, pyrometry, and gas absorption diagnostics to monitor the sample response in real time. The system is designed to operate under vacuum and reach surface temperatures exceeding 2000 K, enabling conditions relevant to pyrolysis in ablative materials.

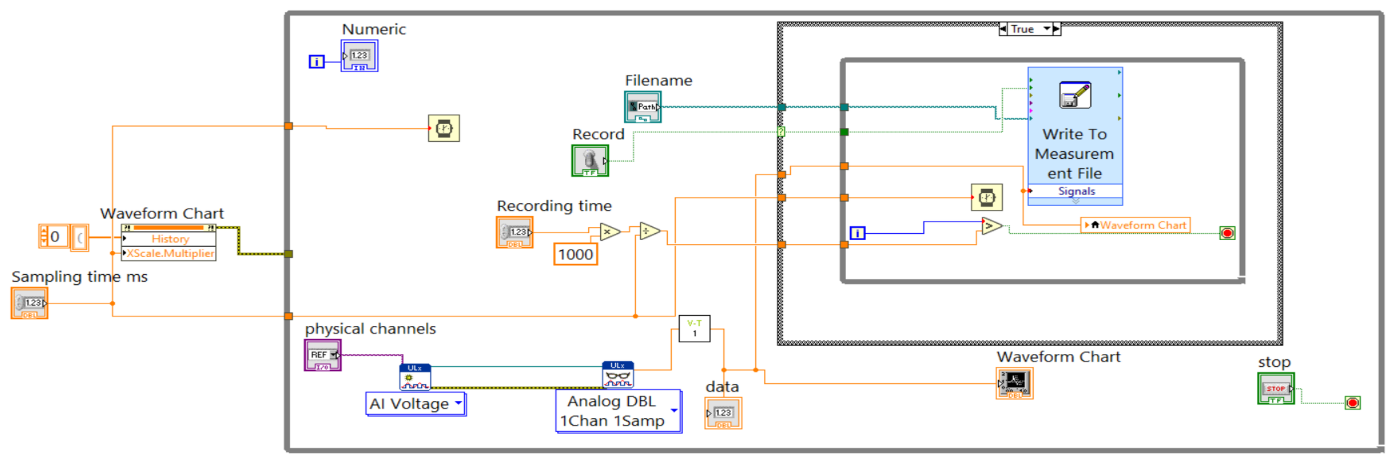


Schematic showing gas injection from below and laser heating from above, with integrated diagnostics under vacuum conditions.



3D rendering of the test chamber and laser alignment system, highlighting the compact design and optical access for diagnostics.

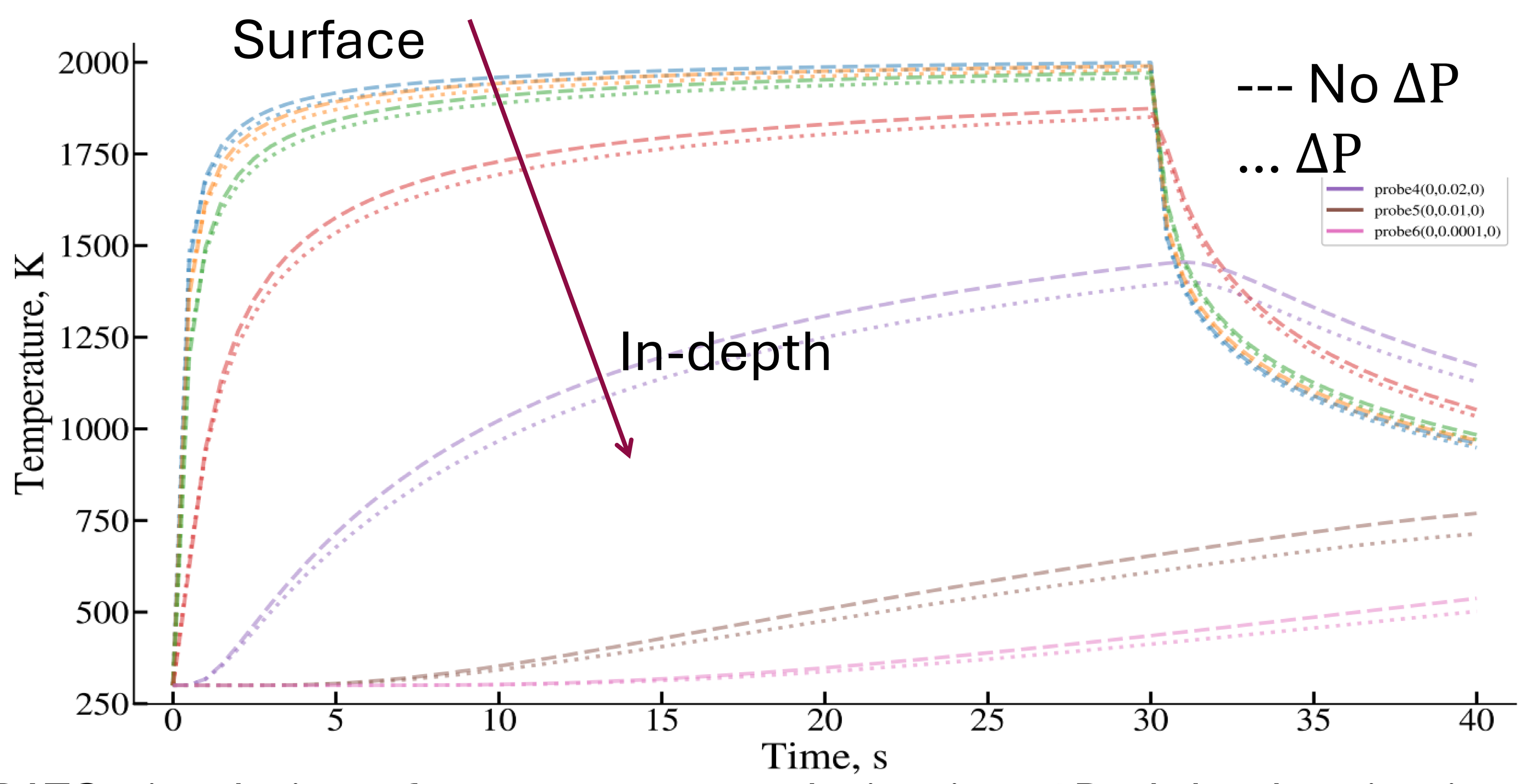
A LabView program is being developed to monitor and control all instruments in the setup. This will enable synchronized operation of diagnostics, automated control of the laser and mass flow controllers, and streamlined test execution. The improved coordination will enhance throughput and simplify postprocessing and data analysis.



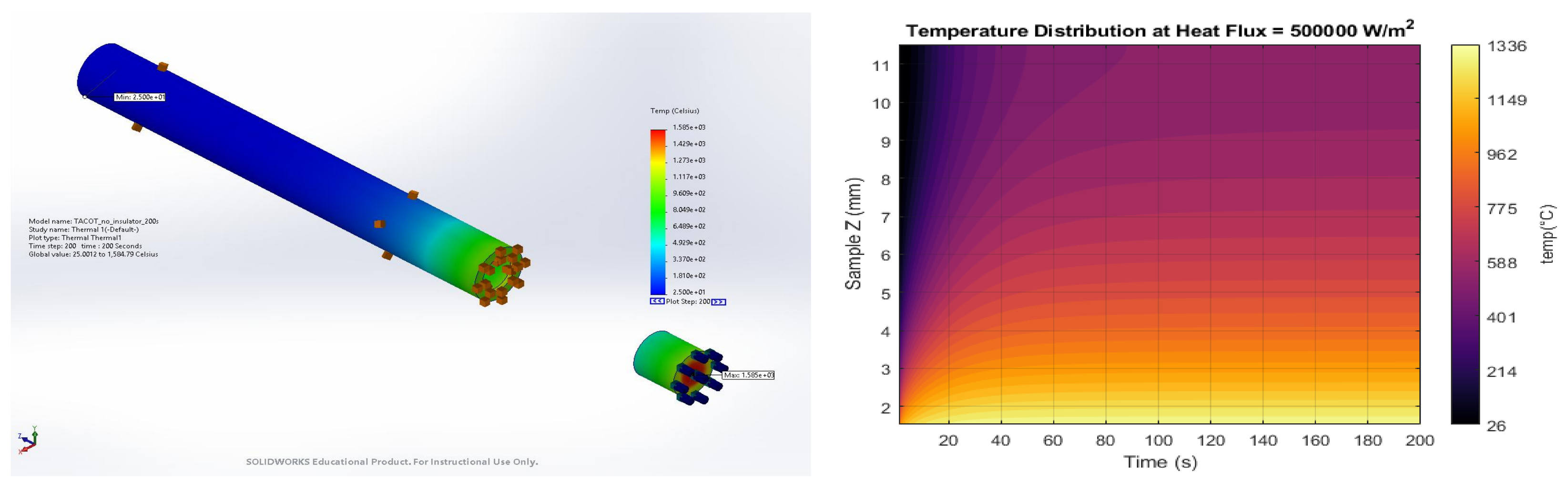
Depiction of the LabView interface for thermocouple control, enabling automated temperature monitoring and system coordination.

Preliminary analyses

Heat transfer simulations have been performed using SolidWorks and PATO. The SolidWorks model employs a 3D geometry with an imposed surface heat flux to represent the laser and includes re-radiation from external surfaces. In parallel, PATO simulations focus on a 1D slab configuration to capture internal conduction and the influence of gas flow through the porous material.



PATO simulation of temperature evolution in a 1D slab, showing internal heating and gas flow effects.



SolidWorks simulation of surface heating and in-depth conduction.

References

[1] F. Torres-Herrador et al. , 13th Ablation Workshop, Nov. 2023
[2] H. X. Varona et al. , 14th Ablation Workshop, Nov. 2024
[3] A. Esposito et al. , Fluids, vol. 5, June 2020